

# Preface

My first book, “*μ C/OS, The Real-Time Kernel*” is now 6 years old and the publisher has sold well over 15,000 copies around the world. When I was asked to do a second edition, I thought it would be a fairly straightforward task; a few corrections here and there, clarify a few concepts, add a function or two to the kernel, etc. If you have a copy of the first edition, you will notice that “*μ C/OS-II, The Real-Time Kernel*” is in fact a major revision. For some strange reason, I wasn’t satisfied with minor corrections. Also, when my publisher told me that this time, the book would be a ‘hard cover’, I really wanted to give you your money’s worth. In all, I added more than 200 new pages, and re-wrote the majority of the pages I did keep. I added a porting guide to help you port *μC/OS-II* to the processor of your choice. Also, I added a chapter that will guide you through upgrading a *μC/OS* port to *μC/OS-II*.

The code for *μ C/OS-II* is basically the same as that of *μC/OS* except that it contains a number of new and useful features, is much better commented, and should be easier to port to processor architectures. *μC/OS-II* offers all the features provided in *μ C/OS* as well as the following new features:

- A fixed-sized block memory manager,
- A service to allow a task to suspend its execution for a certain amount of time (specified in hours, minutes, seconds and milliseconds),
- User definable ‘callout’ functions that are invoked when:
  - a task is created,
  - a task is deleted,
  - a context switch is performed,
  - a clock tick occurs.
- A new task create function that provides additional features,
- Stack checking,
- A function returning the version of *μC/OS-II*,
- And more.

## *μC/OS-II Goals*

Probably the most important goal of *μ C/OS-II* was to make it backward compatible with *μ C/OS* (at least from an application’s standpoint). A *μ C/OS* port might need to be modified to work with *μ C/OS-II* but at least, the application code should require only minor changes (if any). Also, because *μ C/OS-II* is based on the same core as *μ C/OS*, it is just as reliable. I added conditional compilation to allow you to further reduce the amount of RAM (i.e. data space) needed by *μ C/OS-II*. This is especially useful when you have resource limited products. I also added the feature described in the previous section and cleaned up the code.

Where the book is concerned, I wanted to clarify some of the concepts described in the first edition and provide additional explanations about how *μ C/OS-II* works. I had numerous requests about doing a chapter on how to port *μ C/OS* and thus, such a chapter has been included in this book for *μ C/OS-II*.

## ***Intended Audience***

This book is intended for embedded system programmers, consultants and students interested in realtime operating systems.  $\mu$  C/OS-II is a high performance, deterministic real-time kernel and can be embedded in commercial products (see Appendix F, *Licensing*). Instead of writing your own kernel, you should consider  $\mu$  C/OS-II. You will find, as I did, that writing a kernel is not as easy as it first looks.

I'm assuming that you know C and have a minimum knowledge of assembly language. You should also understand microprocessor architectures.

## ***What you will need to use $\mu$ C/OS-II***

The code supplied with this book assumes that you will be using an IBM-PC/AT or compatible (80386 Minimum) computer running under DOS 4.x or higher. The code was compiled with Borland International's C++ V3.1. You should have about 5 MBytes of free disk space on your hard drive. I actually compiled and executed the sample code provided in this book in a DOS window under Windows 95.

To use  $\mu$  C/OS-II on a different target processor (than a PC), you will need to either port  $\mu$  C/OS-II to that processor yourself or, obtain one from  $\mu$  C/OS-II official WEB site at <http://www.uCOS-II.com>. You will also need appropriate software development tools such as an ANSI C compiler, an assembler, linker/locator and some way of debugging your application.

## ***The $\mu$ C/OS Story***

Many years ago, I designed a product based on an Intel 80C188 at Dynalco Controls and I needed a real-time kernel. At my previous employer, I had been using a well known kernel (let's call it kernel 'A') but, found it to be too expensive for the application I was designing. We then found a lower cost kernel (\$1000 at the time) and started our design with it. Let's call this kernel, kernel 'B'. We spent about two months trying to get a couple of very simple tasks to run. We were calling the vendor almost on a daily basis to get help making this work. The vendor claimed that this kernel was written in C. However, we had to initialize every single object using assembly language code. Although the vendor was very patient, we decided that we had enough of this. Our product was falling behind schedule and we really didn't want to spend our time debugging this low cost kernel. It turns out that we were one of this vendor's first customer and the kernel was really not fully tested and debugged!

To get back on track, we decided to go back and use kernel 'A'. The cost was about \$5000 for development seat and we had to pay a per usage fee of about \$200 for each unit that we shipped! This was a lot of money at the time, but it bought us some peace of mind. We got the kernel up and running in about 2 days! Three months into the project, one of our engineers discovered what looked like a bug in the kernel. We sent the code to the vendor and sure enough, the bug was confirmed as being in the kernel. The vendor provided a 90 day warranty but, that had expired so, in order to get support, we had to pay an addition \$500 per year for 'maintenance'. We argued with the salesperson for a few months that they should fix the bug since we were actually doing them a favor. They wouldn't budge! Finally, we gave in, we bought the maintenance contract and the vendor fixed the bug six months later! Yes, six months later. We were furious but most importantly, late delivering our product. In all, it took close to a year to get our product to work reliably with kernel 'A'. I must admit, however, that we never had any problems with it since.

As this was going on, I naively thought, "Well, it can't be that difficult to write a kernel. All it needs to do is save and restore processor registers". That's when I decided to try it out and write my own (part time at night and on weekends). It took me about a year to get the kernel to be just as good (and in some ways better) than kernel 'A'. I didn't want to start a company and sell it because there were already about 50 kernels out there so, why have another one?

I then thought of writing a paper for a magazine. I first went to the "C User's Journal (CUJ)" (the kernel was written in C) which, I had heard, was offering \$100 per published page when other magazines were only paying \$75 per page. My paper had 70 or so pages so, that would be a nice compensation for all the time I spent working on my kernel.

Unfortunately, the article was rejected! There were two reasons. First, the article was too long and the magazine didn't want to publish a series. Second, they didn't want to have 'another kernel article'.

I then decided to turn to Embedded Systems Programming (ESP) magazine because my kernel was designed for embedded systems. I contacted the editor of ESP (Mr. Tyler Sperry) and told him that I had this kernel I wanted to publish in his magazine. I got the same response from Tyler as I did from the C Journal: "Not another kernel article?" I told him that this kernel was different, it was preemptive, it was comparable to many commercial kernels and that he could put the source code on the ESP BBS (Bulletin Board Service). I was calling Tyler two or three times a week (basically begging him) until he finally gave in (he was probably tired of having me call him) and decide to publish the article. My article got edited down from 70 pages to about 30 pages and was published in two consecutive months (May 1992 and June 1992). The article was probably the most popular article in 1992. ESP had over 500 downloads of the code from the BBS in the first month. Tyler may have feared for his life because kernel vendors were upset that he published a kernel in his magazine. I guess that these vendors must have recognized the quality and capabilities of  $\mu$  C/OS (was called  $\mu$  COS then). The article was really the first that exposed the internals of a real-time kernel so, some of the secrets were out.

Just about the time the article came out in ESP, I got a call back from Dr. Bernard Williams at R&D Publications (publisher of CUJ), 6 months after the initial contact with CUJ. He had left a message with my wife and told her that he was interested in the article!?! I called him back and told him something like: "Don't you think you are a little bit late with this? The article is being published in ESP." Berney said: "No, No, you don't understand, because the article is so long, I want to make a book out of it." Initially, Berney simply wanted to publish what I had (as is) so the book would only have 80 or so pages. I said to him, "If I going to write a book, I want to do it right." I then spent about 6 months adding contents to what is now know as the first edition. In all, the book had about 250 pages to it. I changed the name of  $\mu$  COS to  $\mu$  C/OS because ESP readers had been calling it 'Mucus' which didn't sound too healthy! Come to think of it, maybe it was a kernel vendor that first came up with the name. Anyway,  $\mu$  C/OS, *The Real-Time Kernel* was then born. Sales were somewhat slow to start. Berney and I projected that we would sell about 4000 to 5000 copies in the life of the book but at that rate, we would be lucky if it sold 2000 copies. Berney insisted that these things take time to get known so, he continued advertising in CUJ for about a year.

A month or so before the book came out, I went to my first Embedded Systems Conference (ESC) in Santa Clara, CA (September 1992). I then met Tyler Sperry for the first time and I showed him the first draft copy of my book. He very quickly glanced at it and said something like: "Would you like to speak at the next Embedded Systems Conference in Atlanta?" Not knowing any better, I said "Sure, what should I talk about?" He said what about "Using small real-time kernels?" I said "Fine". On the trip back from California, I was thinking "What did I get myself into? I've never spoke in front of a bunch of people before! What if I make a fool of myself? What if what I speak about is common knowledge? Those people pay good money to attend this conference." For the next six months, I prepared my lecture. At the conference, I had about 70+ attendees. In the first twenty minutes I must have lost one pound of sweat. After my lecture, I had a crowd of about 15 or so people come up to me and say that they were very pleased with the lecture and liked my book. I got re-invited back to the conference but could not attend the one in Santa Clara that year (i.e. 1993). I was able to attend the next conference in Boston (1994) and I have been a regular speaker at ESC ever since. For the past couple of years, I've been on the conference Advisory Committee. I now do at least 3 lectures at every conference and each have average attendance of between 200 and 300 people! My lectures are almost always ranked amongst the top 10% of the conference.

To date, we sold well over 15,000 copies of  $\mu$  C/OS, *The Real-Time Kernel* around the world. I received and answered well over 1000 e-mails from the following countries:

In 1995,  $\mu$  C/OS, *The Real-Time Kernel* was translated in Japanese and published in a magazine called *Interface* in Japan.  $\mu$  C/OS has been ported to the following processors:

- Analog Devices AD21xx
- Advanced Risc Machines ARM6, ARM7
- Hitachi 64180, H8/3xx, SH series
- Intel 80x86 (Real and PM), Pentium, PentiumII, 8051, 8052, MCS-251, 80196, 8096
- Mitsubishi M16 and M32

Motorola PowerPC, 68K, CPU32, CPU32+, 68HC11, 68HC16  
Philips XA  
Siemens 80C166 and TriCore  
Texas instruments TMS320  
Zilog Z-80 and Z-180  
And more.

In 1994, I decided to write my second book: *Embedded Systems Building Blocks, Complete and Ready-to-Use Modules in C* (ESBB) and contains over 600 pages. For some reason, ESBB has not been as popular as  $\mu$ C/OS although it contains as much valuable information not found anywhere else. I always thought that it would be an ideal book for people just starting in the embedded world.

In 1998, I opened the official  $\mu$ C/OS WEB site [www.uCOS-II.com](http://www.uCOS-II.com). I intend this site to contain ports, application notes, links, answers to frequently asked questions (FAQs), upgrades for both  $\mu$ C/OS and  $\mu$ C/OS-II, and more. All I need is time!

Back in 1992, I never imagined that writing an article would have changed my life as it did. I met a lot of very interesting people and made a number of good friends in the process. I still answer every single e-mail that I receive. I believe that if you take the time to write to me then I owe you a response. I hope you enjoy this book.

## ***Acknowledgements***

First and foremost, I would like to thank my wife for her support, encouragement, understanding and especially patience. Manon must have heard the words “ Just one more week!” about a dozen times while I was writing this book. I would also like to thank my children James (age 8) and Sabrina (age 4) for putting up with the long hours I had to spend in front of the computer. I hope one day they will understand.

I would also like to thank Mr. Niall Murphy for carefully reviewing most of the chapters and providing me with valuable feedback. Special thanks to Mr. Alain Chebrou and Mr. Bob Paddock for passing the code for  $\mu$ C/OS-II through a fine tooth comb.

I would like to thank all the fine people at R&D Technical books for their help in making this book a reality, and also for putting up with my insistence on having things done my way.

Finally, I would like to thank all the people who have purchased  *$\mu$ C/OS, The Real-Time Kernel* as well as *Embedded Systems Building Blocks* and who, by doing so, have encouraged me to pursue this interesting past-time.

# Introduction

This book describes the design and implementation of  $\mu$ C/OS-II (pronounced "Micro C O S 2") which stands for *Micro-Controller Operating System Version 2*.  $\mu$ C/OS-II is based on  $\mu$ C/OS, *The Real-Time Kernel* which was first published in 1992. Thousands of people around the world are using  $\mu$ C/OS in all kinds of applications such as cameras, medical instruments, musical instruments, engine controls, network adapters, highway telephone call boxes, ATM machines, industrial robots, and many more. Numerous colleges and Universities have also used  $\mu$ C/OS to teach students about real-time systems.

$\mu$ C/OS-II is upward compatible with  $\mu$ C/OS (V1.11) but provides many improvements over  $\mu$ C/OS such as the addition of a fixed-sized memory manager, user definable callouts on task creation, task deletion, task switch and system tick, supports TCB extensions, stack checking and, much more. I also added comments to just about every function and I made  $\mu$ C/OS-II much easier to port to different processors. The source code in  $\mu$ C/OS was found in two source files. Because  $\mu$ C/OS-II contains many new features and functions, I decided to split  $\mu$ C/OS-II in a few source files to make the code easier to maintain.

If you currently have an application (i.e. product) that runs with  $\mu$ C/OS, your application should be able to run, virtually unchanged, with  $\mu$ C/OS-II. All of the services (i.e. function calls) provided by  $\mu$ C/OS have been preserved. You may, however, have to change include files and product build files to 'point' to the new file names.

This book contains ALL the source code for  $\mu$ C/OS-II and a port for the Intel 80x86 processor running in *Real-Mode* and for the *Large Model*. The code was developed on a PC running the Microsoft Windows 95 operating system. Examples run in a DOS compatible box under the Windows 95 environment. Development was done using the Borland International C/C++ compiler version 3.1. Although  $\mu$ C/OS-II was developed and tested on a PC,  $\mu$ C/OS-II was actually targeted for embedded systems and can easily be ported to many different processor architectures.

## $\mu$ C/OS-II features:

### Source Code:

As I mentioned previously, this book contains ALL the source code for  $\mu$ C/OS-II. I went through a lot of efforts to provide you with a high quality 'product'. You may not agree with some of the style constructs that I use but you should agree that the code is both clean and very consistent. Many commercial real-time kernels are provided in source form. I challenge you to find any such code that is as neat, consistent, well commented and organized as  $\mu$ C/OS-II's. Also, I believe that simply giving you the source code is not enough. You need to know how the code works and how the different pieces fit together. You will find this type of information in this book. The organization of a real-time kernel is not always apparent by staring at many source files and thousands of lines of code.

### Portable:

Most of  $\mu$ C/OS-II is written in highly portable ANSI C, with target microprocessor specific code written in assembly language. Assembly language is kept to a minimum to make  $\mu$ C/OS-II easy to port to other processors. Like  $\mu$ C/OS,  $\mu$ C/OS-II can be ported to a large number of microprocessors as long as the microprocessor provides a stack pointer and the CPU registers can be pushed onto and popped from the stack. Also, the C compiler should either provide in-line assembly or language extensions that allow you to enable and disable interrupts from C.  $\mu$ C/OS-II can run on most 8-bit, 16-bit, 32-bit or even 64-bit microprocessors or micro-controllers and, DSPs.

All the ports that currently exist for  $\mu$ C/OS can be easily converted to  $\mu$ C/OS-II in about an hour. Also, because  $\mu$ C/OS-II is upward compatible with  $\mu$ C/OS, your  $\mu$ C/OS applications should run on  $\mu$ C/OS-II with few or no changes. Check for the availability of ports on the  $\mu$ C/OS-II Web site at 'www.uCOS-II.com'.

**ROMable:**

$\mu$  C/OS-II was designed for embedded applications. This means that if you have the proper tool chain (i.e. C compiler, assembler and linker/locator), you can embed  $\mu$  C/OS-II as part of a product.

**Scalable:**

I designed  $\mu$  C/OS-II so that you can use only the services that you need in your application. This means that a product can have just a few of  $\mu$  C/OS-II's services while another product can have the full set of features. This allows you to reduce the amount of memory (both RAM and ROM) needed by  $\mu$  C/OS-II on a product per product basis. Scalability is accomplished with the use of conditional compilation. You simply specify (through **#define** constants) which features you need for your application/product. I did everything I could to reduce both the code and data space required by  $\mu$  C/OS-II.

**Preemptive:**

μ C/OS-II is a fully -preemptive real-time kernel. This means that μ C/OS-II always runs the highest priority task that is ready. Most commercial kernels are preemptive and μ C/OS-II is comparable in performance with many of them.

**Multi-tasking:**

μ C/OS-II can manage up to 64 tasks, however, the current version of the software reserves eight (8) of these tasks for system use. This leaves your application with up to 56 tasks. Each task has a unique priority assigned to it which means that μ C/OS-II cannot do round robin scheduling. There are thus 64 priority levels.

**Deterministic:**

Execution time of all μ C/OS-II functions and services are deterministic. This means that you can always know how much time μ C/OS-II will take to execute a function or a service. Furthermore, except for one service, execution time of all μ C/OS-II services do not depend on the number of tasks running in your application.

**Task stacks:**

Each task requires its own stack, however, μ C/OS-II allows each task to have a different stack size. This allows you to reduce the amount of RAM needed in your application. With μ C/OS-II's stack checking feature, you can determine exactly how much stack space each task actually requires.

**Services:**

μC/OS-II provides a number of system services such as mailboxes, queues, semaphores, fixed-sized memory partitions, time related functions, etc.

**Interrupt Management:**

Interrupts can suspend the execution of a task and, if a higher priority task is awakened as a result of the interrupt, the highest priority task will run as soon as all nested interrupts complete. Interrupts can be nested up to 255 levels deep.

**Robust and reliable:**

μ C/OS-II is based on μ C/OS which has been used in hundreds of commercial applications since 1992. μ C/OS-II uses the same core and most of the same functions as μ C/OS yet offers more features.

## Figures, Listings and Tables Convention:

You will notice that when I reference a specific element in a figure, I use the letter 'F' followed by the figure number. A number in parenthesis following the figure number represents a specific element in the figure that I am trying to bring your attention to. F1-2(3) thus means look at the third item in Figure 1-2.

Listings and tables work exactly the same way except that a listing start with the letter 'L' and a table with the letter 'T'.

## Source Code Conventions:

All  $\mu$ C/OS-II objects (functions, variables, **#define** constants and macros) start with **OS** indicating that they are *Operating System* related.

Functions are found in alphabetical order in all the source code files. This allows you to quickly locate any function.

You will find the coding style I use is very consistent. I have been adopting the K&R style for many years. However, I did add some of my own enhancements to make the code (I believe) easier to read and maintain. Indention is always 4 spaces, TABs are never used, always at least one space around an operator, comments are always to the right of code, comment blocks are used to describe functions, etc.

The following table provides the acronyms, abbreviations and mnemonics (AAMs) used in this book. I combine some of these AAMs to make up function, variable and **#define** names in a hierarchical way. For example, the function **OSMboxCreate()** reads like this: the function is part of the operating system (**OS**), it is related to the mailbox services (**Mbox**) and the operation performed is to **Create** a mailbox. Also, all services that have similar operation share the same name. For example, **OSSemCreate()** and **OSMboxCreate()** perform the same operation but on their respective objects (i.e. semaphore and mailbox, respectively).



<b>Acronym, Abbreviation or Mnemonic</b>	<b>Meaning</b>
Addr	Address
Blk	Block
Chk	Check
Clr	Clear
Cnt	Count
CPU	Central Processing Unit
Ctr	Counter
Ctx	Context
Cur	Current
Del	Delete
Dly	Delay
Err	Error
Ext	Extension
FP	Floating-Point
Grp	Group
HMSM	Hours Minutes Seconds Milliseconds
ID	Identifier
Init	Initialize
Int	Interrupt
ISR	Interrupt Service Routine
Max	Maximum
Mbox	Mailbox
Mem	Memory
Msg	Message
N	Number of
Opt	Option
OS	Operating System
Ovf	Overflow
Prio	Priority
Ptr	Pointer
Q	Queue
Rdy	Ready
Req	Request
Sched	Scheduler
Sem	Semaphore
Stat	Status or statistic
Stk	Stack
Sw	Switch
Sys	System
Tbl	Table
TCB	Task Control Block
TO	Timeout

**Acronyms, abbreviations and mnemonics used in this book**

# Chapter contents:

## **Chapter 1, Sample Code**

This chapter is designed to allow you to quickly experiment with and use  $\mu$ C/OS-II. The chapter starts by showing you how to install the distribution diskette and describe the directories created. I then explain some of the coding conventions used. Before getting into the description of the examples, I describe the code used to access some of the services provided on a PC.

## **Chapter 2, Real-Time Systems Concepts**

Here, I introduce you to some real-time systems concepts such as foreground/background systems, critical sections, resources, multitasking, context switching, scheduling, reentrancy, task priorities, mutual exclusion, semaphores, intertask communications, interrupts and more.

## **Chapter 3, Kernel Structure**

This chapter introduces you to  $\mu$ C/OS-II and its internal structure. You will learn about tasks, task states, task control blocks, how  $\mu$ C/OS-II implements a ready list, task scheduling, the idle task, how to determine CPU usage, how  $\mu$ C/OS-II handles interrupts, how to initialize and start  $\mu$ C/OS-II and more.

## **Chapter 4, Task Management**

This chapter describes  $\mu$ C/OS-II's services to create a task, delete a task, check the size of a task's stack, change a task's priority, suspend and resume a task, and get information about a task.

## **Chapter 5, Time Management**

This chapter describes how  $\mu$ C/OS-II can suspend a task's execution until some user specified time expires, how such a task can be resumed and how to get and set the current value of a 32-bit tick counter.

## **Chapter 6, Intertask Communication and Synchronization**

This chapter describes  $\mu$ C/OS-II's services to have tasks and ISRs (Interrupt Service Routines) communicate with one another and share resources. You will learn how semaphores, message mailboxes and message queues are implemented.

## **Chapter 7, Memory Management**

This chapter describes  $\mu$ C/OS-II's dynamic memory allocation feature using fixed-sized memory blocks.

## **Chapter 8, Porting $\mu$ C/OS-II**

This chapter describes in general terms what needs to be done to adapt  $\mu$ C/OS-II to different processor architectures.

### **Chapter 9, 80x86 Large Model Port**

This chapter describes how  $\mu$  C/OS-II was ported to the Intel/AMD 80x86 processor architecture running in real-mode and for the large model. Code and data space memory usage is provided as well as execution times for each of the functions.

### **Chapter 10, Upgrading from $\mu$ C/OS to $\mu$ C/OS-II**

This chapter describes how easy it is to migrate a port done for  $\mu$  C/OS to work with  $\mu$  C/OS-II.

### **Chapter 11, Reference Manual**

This chapter describes each of the functions (i.e. services) provided by  $\mu$  C/OS-II from an application developer's standpoint. Each function contains a brief description, its prototype, the name of the file where the function is found, a description of the function arguments and the return value, special notes and examples.

### **Chapter 12, Configuration Manual**

This chapter describes each of the #define constants used to configure  $\mu$  C/OS-II for your application. Configuring  $\mu$  C/OS-II allows you to use only the services required by your application. This gives you the flexibility to reduce  $\mu$  C/OS-II's memory footprint (code and data space).

### **Appendix A, Example Source Code**

Fully commented source code for the examples and PC services (see Chapter 1) is provided in this appendix and consist of 11 files.

### **Appendix B, $\mu$ C/OS-II Microprocessor Independent Source Code**

The source code for the portion of  $\mu$  C/OS-II that is not dependent on any specific processor is provided in this appendix and consist of 9 files

### **Appendix C, 80x86 Real-Mode, Large Model Source Code**

The source code for the 80x86 processor dependent functions is found in this appendix and consist of three files.

### **Appendix D, TO and HPLISTC**

Presents two DOS utilities that I use: TO and HPLISTC. TO is a utility that I use to quickly move between MS-DOS directories without having to type the CD (change directory) command. HPLISTC is a utility to print C source code in compressed mode (i.e. 17 CPI) and allows you to specify page breaks. The printout is assumed to be to a Hewlett Packard (HP) Laserjet type printer.

### **Appendix E, Bibliography**

This section provides a bibliography of reference material that you may find useful if you are interested in getting further information about embedded real-time systems.

### **Appendix F, Licensing**

Describes the licensing policy for distributing  $\mu$  C/OS-II in source and object form.

## **$\mu$ C/OS-II Web site:**

To better support you, I created the  $\mu$  C/OS-II WEB site ([www.uCOS-II.com](http://www.uCOS-II.com)). You can thus obtain information about:

- News on  $\mu$  C/OS and  $\mu$  C/OS-II,
- Upgrades,
- Bug fixes,
- Availability of ports,
- Answers to frequently asked questions (FAQs),
- Application notes,
- Books,
- Classes,

- Links to other WEB sites, and
- More.

## *Chapter 1.*

# *Sample Code*

This chapter provides you with three examples on how to use  $\mu$  C/OS-II. I decided to include this chapter early in the book to allow you to start using  $\mu$  C/OS-II as soon as possible. Before getting into the examples, however, I will describe some of the conventions I use throughout this book.

The sample code was compiled using the Borland International C/C++ compiler V3.1 and options were selected to generate code for an Intel/AMD 80186 processor (Large memory model). The code was actually ran and tested on a 300 MHz Intel Pentium-II based PC with can be viewed as a super fast 80186 processor (at least for my purpose). I chose a PC as my target system for a number of reasons. First and foremost, it's a lot easier to test code on a PC than on any other embedded environment (i.e., evaluation board, emulator etc.): there are no EPROMs to burn, no downloads to EPROM emulators, CPU emulators, etc. You simply compile, link, and run. Second, the 80186 object code (Real Mode, Large Model) generated using the Borland C/C++ compiler is compatible with all 80x86 derivative processors from Intel, AMD or Cyrix.

## ***1.00 Installing $\mu$ C/OS-II***

R & D Publications, Inc. has included a Companion Diskette to  $\mu$  C/OS-II, The Real-Time Kernel. The diskette is in MS-DOS format and contains all the source code provided in this book. It is assumed that you have a DOS or Windows 95 based computer system running on an 80x86, Pentium or Pentium-II processor. You will need less than about 5 Mbytes of free disk space to install  $\mu$  C/OS-II and its source files on your system.

Before starting the installation, make a backup copy of the companion diskette. To install the code provided on the companion diskette, follow these steps:

- 1) Load DOS (or open a DOS box in Windows 95) and specify the C: drive as the default drive.  
Insert the companion diskette in drive **A:**  
Enter **A:INSTALL [drive]**

Note that **[drive]** is an optional drive letter indicating the destination disk on which the source code provided in this book will be installed. If you do not specify a drive, the source code will be installed on the current drive.

**INSTALL** is a DOS batch file called **INSTALL.BAT** and is found in the root directory of the companion diskette. **INSTALL.BAT** will create a **\SOFTWARE** directory on the specified destination drive. **INSTALL.BAT** will then change the directory to **\SOFTWARE** and copy the file **uCOS-II.EXE** from the A: drive to this directory. **INSTALL.BAT** will then execute **uCOS-II.EXE**, which will create all other directories under **\SOFTWARE** and transfer all source and executable files provided in this book. Upon completion, **INSTALL.BAT** will delete **uCOS-II.EXE** and change the directory to **\SOFTWARE\uCOS-II\EX1\_x86L** where the first example code is found.

Make sure you read the **READ.ME** file on the companion diskette for last minute changes and notes.

Once **INSTALL.BAT** has completed, your destination drive will contain the following subdirectories:

**\SOFTWARE**

The main directory from the root where all software-related files are placed.

**\SOFTWARE\BLOCKS**

The main directory where all 'Building Blocks' are located. With  $\mu$  C/OS-II, I included a 'building block' that handles DOS-type compatible functions that are used by the example code.

**\SOFTWARE\BLOCKS\TO**

This directory contains the files for the TO utility (see Appendix E, *TO*). The source file is **TO.C** and is found in the **\SOFTWARE\TO\SOURCE** directory. The DOS executable file (**TO.EXE**) is found in the **\SOFTWARE\TO\EXE** directory. Note that TO requires a file called **TO.TBL** which must reside on your root directory. An example of **TO.TBL** is also found in the **\SOFTWARE\TO\EXE** directory. You will need to move **TO.TBL** to the root directory if you are to use **TO.EXE**.

**\SOFTWARE\uCOS-II**

The main directory where all  $\mu$  C/OS-II files are located.

**\SOFTWARE\uCOS-II\EX1\_x86L**

This directory contains the source code for EXAMPLE #1 (see section 1.07, *Example #1*) which is intended to run under DOS (or a DOS window under Windows 95).

**\SOFTWARE\uCOS-II\EX2\_x86L**

This directory contains the source code for EXAMPLE #2 (see section 1.08, *Example #2*) which is intended to run under DOS (or a DOS window under Windows 95).

**\SOFTWARE\uCOS-II\EX3\_x86L**

This directory contains the source code for EXAMPLE #3 (see section 1.09, *Example #3*) which is intended to run under DOS (or a DOS window under Windows 95).

**\SOFTWARE\uCOS-II\Ix86L**

This directory contains the source code for the processor dependent code (a.k.a. the port) of  $\mu$  C/OS-II for an 80x86 Real-Mode, Large Model processor.

**\SOFTWARE\uCOS-II\SOURCE**

This directory contains the source code for processor independent portion of  $\mu$  C/OS-II. This code is fully portable to other processor architectures.

## ***1.01 INCLUDES.H***

You will notice that every .C file in this book contains the following declaration:

```
#include "includes.h"
```

**INCLUDES.H** allows every .C file in your project to be written without concern about which header file will actually be included. In other words, **INCLUDES.H** is a Master include file. The only drawback is that **INCLUDES.H** includes header files that are not pertinent to some of the .C file being compiled. This means that each file will require extra time to compile. This inconvenience is offset by code portability. There is an **INCLUDES.H** for every example provided in this book. In other words, you will find a different copy of **INCLUDES.H** in `\SOFTWARE\uCOS-II\EX1_x86L`, `\SOFTWARE\uCOS-II\EX2_x86L` and `\SOFTWARE\uCOS-II\EX3_x86L`. You can certainly edit **INCLUDES.H** to add your own header files.

## *1.02 Compiler Independent Data Types*

Because different microprocessors have different word length, the port of  $\mu$  C/OS-II includes a series of type definitions that ensures portability (see `\SOFTWARE\uCOS-II\Ix86L\OS_CPU.H` for the 80x86 real-mode, large model). Specifically,  $\mu$  C/OS-II's code never makes use of C's **short**, **int** and, **long** data types because they are inherently non-portable. Instead, I defined integer data types that are both portable and intuitive as shown in listing 1.1. Also, for convenience, I have included floating-point data types even though  $\mu$  C/OS-II doesn't make use of floating-point.



```

typedef unsigned char  BOOLEAN;
typedef unsigned char  INT8U;
typedef signed   char  INT8S;
typedef unsigned int   INT16U;
typedef signed   int   INT16S;
typedef unsigned long  INT32U;
typedef signed   long  INT32S;
typedef float         FP32;
typedef double        FP64;

#define BYTE          INT8S
#define UBYTE         INT8U
#define WORD          INT16S
#define UWORD         INT16U
#define LONG          INT32S
#define ULONG         INT32U

```

### Listing 1.1, Portable data types.

The **INT16U** data type, for example, always represents a 16-bit unsigned integer.  $\mu$  C/OS-II and your application code can now assume that the range of values for variables declared with this type is from 0 to 65535. A  $\mu$ C/OS-II port to a 32-bit processor could mean that an **INT16U** would be declared as an **unsigned short** instead of an **unsigned int**. Where  $\mu$  C/OS-II is concerned, however, it still deals with an **INT16U**. Listing 1.1 provides the declarations for the 80x86 and the Borland C/C++ compiler as an example.

For backward compatibility with  $\mu$  C/OS, I also defined the data types **BYTE**, **WORD**, **LONG** (and their unsigned variations). This allows you to migrate  $\mu$  C/OS code to  $\mu$  C/OS-II without changing all instances of the old data types to the new data types. I decided to make this transition and break away from the old style data types because I believe that this new scheme makes more sense and is more obvious. A **WORD** to some people may mean a 32-bit value whereas I originally intended it to mean a 16-bit value. With the new data types, there should be no more confusion.

## 1.03 Global Variables

Following is a technique that I use to declare global variables. As you know, a global variable needs to be allocated storage space in RAM and must be referenced by other modules using the C keyword `extern`. Declarations must thus be placed in both the .C and the .H files. This duplication of declarations, however, can lead to mistakes. The technique described in this section only requires a single declaration in the header file, but is a little tricky to understand. However, once you know how this technique works you will apply it mechanically.

In all .H files that define global variables, you will find the following declaration:

```

#ifndef   xxx_GLOBALS
#define   xxx_EXT
#else

```

```
#define xxx_EXT extern
#endif
```

## Listing 1.2, Defining global macros.

Each variable that needs to be declared global will be prefixed with **xxx\_EXT** in the .H file. 'xxx' represents a prefix identifying the module name. The module's .C file will contain the following declaration:

```
#define xxx_GLOBALS
#include "includes.h"
```

When the compiler processes the .C file it forces **xxx\_EXT** (found in the corresponding .H file) to "nothing" (because **xxx\_GLOBALS** is defined) and thus each global variable will be allocated storage space. When the compiler processes the other .C files, **xxx\_GLOBALS** will not be defined and thus **xxx\_EXT** will be set to **extern**, allowing you to reference the global variable. To illustrate the concept, let's look at **uCOS\_II.H** which contains the following declarations:

```
#ifndef OS_GLOBALS
#define OS_EXT
#else
#define OS_EXT extern
#endif

OS_EXT INT32U OSIdleCtr
OS_EXT INT32U OSIdleCtrRun;
OS_EXT INT32U OSIdleCtrMax;
```

**uCOS\_II.c** contains the following declarations:

```
#define OS_GLOBALS
#include "includes.h"
```

When the compiler processes **uCOS\_II.C** it makes the header file (**uCOS\_II.H**) appear as shown below because **OS\_EXT** is set to "nothing":

```
INT32U      OSIdleCtr
INT32U      OSIdleCtrRun;
INT32U      OSIdleCtrMax;
```

The compiler is thus told to allocate storage for these variables. When the compiler processes any other .C files, the header file (**uCOS\_II.H**) looks as shown below because **OS\_GLOBALS** is not defined and thus **OS\_EXT** is set to extern.

```
extern INT32U      OSIdleCtr
extern INT32U      OSIdleCtrRun;
extern INT32U      OSIdleCtrMax;
```

In this case, no storage is allocated and any .C file can access these variables. The nice thing about this technique is that the declaration for the variables is done in only one file, the .H file.

## ***1.04 OS\_ENTER\_CRITICAL() and OS\_EXIT\_CRITICAL()***

Throughout the source code provided in this book, you will see calls to the following macros: **OS\_ENTER\_CRITICAL()** and **OS\_EXIT\_CRITICAL()**. **OS\_ENTER\_CRITICAL()** is a macro that disables interrupts and **OS\_EXIT\_CRITICAL()** is a macro that enables interrupts. Disabling and enabling interrupts is done to protect critical sections of code. These macros are obviously processor specific and are different for each processor. These macros are found in **OS\_CPU.H**. Listing 1.3 shows the declarations of these macros for the 80x86 processor. Section 9.03.02 discusses why there are two ways of declaring these macros.

```
#define OS_CRITICAL_METHOD    2

#if OS_CRITICAL_METHOD == 1
#define OS_ENTER_CRITICAL()  asm CLI
#define OS_EXIT_CRITICAL()   asm STI
#endif

#if OS_CRITICAL_METHOD == 2
#define OS_ENTER_CRITICAL()  asm {PUSHF; CLI}
#define OS_EXIT_CRITICAL()   asm POPF
#endif
```

### **Listing 1.3, Macros to access critical sections.**

Your application code can make use of these macros as long as you realize that they are used to disable and enable interrupts. Disabling interrupts obviously affect interrupt latency so be careful. You can also protect critical sections using semaphores.

## ***1.05 PC Based Services***

The files **PC.C** and **PC.H** (in the **\SOFTWARE\BLOCKS\PC\SOURCE** directory) contain PC compatible services that I used throughout the examples. Unlike the first version of  $\mu$  C/OS-II (i.e.  $\mu$  C/OS), I decided to encapsulate these functions (as they should have been) to avoid redefining them in every example and also, to allow you to easily adapt the code to a different compiler. **PC.C** basically contains three types of services: character based display, elapsed time measurement and, miscellaneous. All functions start with the prefix **PC\_**.

### ***1.05.01 PC Based Services, Character Based Display***

The display functions perform direct writes to video RAM for performance reasons. On a VGA monitor, video memory starts at absolute memory location 0x000B8000 (or using a segment:offset notation, B800:0000). You can use this code on a monochrome monitor by changing the **#define** constant **DISP\_BASE** from 0xB800 to 0xB000.

The display functions in **PC.C** are used to write ASCII (and special) characters anywhere on the screen using X and Y coordinates. A PC's display can hold up to 2000 characters organized as 25 rows (i.e. Y) by 80 columns (i.e. X). Each character requires two bytes to display. The first byte is the character that you want to display while the second byte is an attribute that determines the foreground/background color combination of the character. The foreground color is specified in the lower 4 bits of the attribute while the background color appears in bits 4 to 6. Finally, the most-significant bit determines whether the character will blink (when 1) or not (when 0). You should use the **#define** constants declared in **PC.C** (FGND means foreground and BGND is background). **PC.C** contains the following four functions:

<b>PC_DisPClrScr()</b>	To clear the screen
<b>PC_DisPClrLine()</b>	To clear a single row (or line)
<b>PC_DisPChar()</b>	To display a single ASCII character anywhere on the screen
<b>PC_DisPStr()</b>	To display an ASCII string anywhere on the screen

### ***1.05.02 PC Based Services, Elapsed Time Measurement***

The elapsed time measurement functions are used to determine how much time a function takes to execute. Time measurement is performed by using the PC's 82C54 timer #2. You make time measurement by wrapping the code to measure by the two functions **PC\_ElapsedStart()** and **PC\_ElapsedStop()**. However, before you can use these two functions, you need to call the function **PC\_ElapsedInit()**. **PC\_ElapsedInit()** basically computes the overhead associated with the other two functions. This way, the execution time returned by **PC\_ElapsedStop()** consist exclusively of the code you are measuring. Note that none of these functions are reentrant and thus, you must be careful that you do not invoke them from multiple tasks at the same time. The example in listing 1.4 shows how you could measure the execution time of **PC\_Dispatch()**. Note that time is in microseconds ( $\mu$  S).

```
INT16U time;

PC_ElapsedInit();
.
.
PC_ElapsedStart();
PC_Dispatch(40, 24, 'A', DISP_FGND_WHITE);
time = PC_ElapsedStop();
```

**Listing 1.4, Measuring code execution time.**

### ***1.05.03 PC Based Services, Miscellaneous***

A  $\mu$  C/OS-II application looks just like any other DOS application. In other words, you compile and link your code just as if you would do a single threaded application running under DOS. The .EXE file that you create is loaded and executed by DOS and execution of your application starts from **main()**. Because  $\mu$  C/OS-II performs multitasking and needs to create a stack for each task, the single threaded DOS environment must be stored in case your application wishes to quit  $\mu$  C/OS-II, and return to DOS. Saving the DOS environment is done by calling **PC\_DOSSaveReturn()**. When your application needs to return to DOS (and exit  $\mu$  C/OS-II), you simply call **PC\_DOSReturn()**. **PC.C** makes use of the ANSI C **setjmp()** and **longjmp()** functions to save and restore the DOS environment, respectively. These functions are provided by the Borland C/C++ compiler library and should be available on most other compilers.

You should note that a crashed application or invoking **exit(0)** without using **PC\_DOSReturn()** can leave DOS in a corrupted state. This may lead to a crash of DOS, or the DOS window within Windows 95.

**PC\_GetDateTime()** is a function that obtains the PC's current date and time, and formats this information into an ASCII string. The format is "MM-DD-YY HH:MM:SS" and you will need at least 19 characters (including the NUL character) to hold this string. **PC\_GetDateTime()** uses the Borland

C/C++ library functions **gettime()** and **getdate()** which should have their equivalent on other DOS compilers.

**PC\_GetKey()** is a function that checks to see if a key was pressed and if so, obtains that key, and returns it to the caller. **PC\_GetKey()** uses the Borland C/C++ library functions **kbhit()** and **getch()** which again, have their equivalent on other DOS compilers.

**PC\_SetTickRate()** allows you to change the tick rate for  $\mu$ C/OS-II by specifying the desired frequency. Under DOS, a tick occurs 18.20648 times per second or, every 54.925 mS. This is because the 82C54 chip used didn't get its counter initialized and the default value of 65535 takes effect. Had the chip been initialized with a divide by 59659, the tick rate would have been a very nice 20.000 Hz! I decided to change the tick rate to something more 'exciting' and thus, decided to use about 200 Hz (actually 199.9966). You will note that the function **OSTickISR()** found in **OS\_CPU\_A.ASM** contains code to call the DOS tick handler one time out of 11. This is done to ensure that some of the housekeeping needed in DOS is maintained. You would not need to do this if you were to set the tick rate to 20 Hz. Before returning to DOS, **PC\_SetTickRate()** is called by specifying 18 as the desired frequency. **PC\_SetTickRate()** will know that you actually mean 18.2 Hz and will correctly set the 82C54.

The last two functions in **PC.C** are used to get and set an interrupt vector. Again, I used Borland C/C++ library functions do accomplish this but, the **PC\_VectGet()** and **PC\_VectSet()** can easily be changed to accommo date a different compiler.

## ***1.06 $\mu$ C/OS-II Examples***

The examples provided in this chapter was compiled using the Borland C/C++ V3.1 compiler in a DOS box on a Windows 95 platform. The executable code is found in the OBJ subdirectory of each example's directory. The code was actually compiled under the Borland IDE (Integrated Development Environment) with the following options:

## Compiler:

### Code generation:

Model : Large  
Options : Treat enums as ints  
Assume SS Equals DS : Default for memory model

### Advanced code generation:

Floating point : Emulation  
Instruction set : 80186  
Options : Generate underbars  
Debug info in OBJs  
Fast floating point

### Optimizations:

#### Optimizations:

Global register allocation  
Invariant code motion  
Induction variables  
Loop optimization  
Suppress redundant loads  
Copy propagation  
Dead code elimination  
Jump optimization  
Inline intrinsic functions

#### Register variables:

Automatic

#### Common subexpressions:

Optimize globally

#### Optimize for:

Speed

It is assumed that the Borland C/C++ compiler is installed in the **C:\CPP** directory. If your compiler is located in a different directory, you will need to change the path in the Options/Directories menu of the IDE.

$\mu$  C/OS-II is a scalable operating system which means that the code size of  $\mu$  C/OS-II can be reduced if you are not using all of its services. Code reduction is done by setting the **#defines OS\_???\_EN** to 0 in **OS\_CFG.H**. You do this to disable code generation for the services that you will not be using. The examples in this chapter make use of this feature and thus, each example declares their **OS\_???\_EN** appropriately.

## ***1.07 Example #1***

The first example is found in `\SOFTWARE\uCOS-II\EX1_x86L` and basically consists of 13 tasks (including  $\mu$  C/OS-II's idle task).  $\mu$  C/OS-II creates two 'internal' tasks: the idle task and a task that determines CPU usage. Example #1 creates 11 other tasks. The **TaskStart()** task is created by **main()** and its function is to create the other tasks and display the following statistics on the screen:

- 1) the number of task switches in one second,
- 2) the CPU usage in %,
- 3) the number of context switches,
- 4) the current date and time, and
- 5)  $\mu$  C/OS-II's version.

The **TaskStart()** task also checks to see if you pressed the ESCAPE key indicating your desire to exit the example and return to DOS.

The other 10 tasks are based on the same code, i.e. the function **Task()**. Each of the 10 tasks displays a number (each task has its own number from 0 to 9) at random locations on the screen.

### ***1.07.01 Example #1, main()***

Example #1 does basically the same thing as the first example provided in the first edition of  $\mu$  C/OS, however, I cleaned up some of the code and output to the screen is in color. Also, I decided to use the old data types (i.e. **UBYTE**, **UWORD** etc.) to show that  $\mu$  C/OS-II is backward compatible.

A  $\mu$  C/OS-II application looks just like any other DOS application. You compile and link your code just as if you would do a single threaded application running under DOS. The .EXE file that you create is loaded and executed by DOS, and execution of your application starts from **main()**.



**main()** starts by clearing the screen to ensure we don't have any characters left over from the previous DOS session L1.5(1). Note that I specified to use white letters on a black background. Since the screen will be cleared, I could have simply specified to use a black background and not specify a foreground. If I did this, and you decided to return to DOS then you would not see anything on the screen! It's always better to specify a visible foreground just for this reason.

```
void main (void)
{
    PC_DispcClrScr(DISPC_FGND_WHITE + DISPC_BGND_BLACK);      (1)
    OSInit();                                                  (2)
    PC_DOSSaveReturn();                                       (3)
    PC_VectSet(uCOS, OSCtxSw);                                 (4)
    RandomSem = OSSemCreate(1);                                (5)
    OSTaskCreate(TaskStart,                                   (6)
                  (void *)0,
                  (void *)&TaskStartStk[TASK_STK_SIZE-1],
                  0);
    OSStart();                                                (7)
}
```

### Listing 1.5, main()

A requirement of  $\mu$  C/OS-II is that you call **OSInit()** L1.5(2) before you invoke any of its other services. **OSInit()** creates two tasks: an idle task which executes when no other task is ready-to-run and, a statistic task which computes CPU usage.

The current DOS environment is then saved by calling **PC\_DOSSaveReturn()** L1.5(3). This allows us to return to DOS as if we had never started  $\mu$  C/OS-II. A lot happens in **PC\_DOSSaveReturn()** so you may need to look at the code in listing 1.6 to follow along. **PC\_DOSSaveReturn()** starts by setting the flag **PC\_ExitFlag** to **FALSE** L1.6(1) indicating that we are not returning to DOS. Then, **PC\_DOSSaveReturn()** initializes **OSTickDOSCtr** to 1 L1.6(2) because this variable will be decremented in **OSTickISR()**. A value of 0 would have caused this value to wrap around to 255 when decremented by **OSTickISR()**. **PC\_DOSSaveReturn()** then saves DOS's tick handler in a free vector table L1.6(3)-(4) entry so it can be called by  $\mu$  C/OS-II's tick handler. Next, **PC\_DOSSaveReturn()** calls **setjmp()** L1.6(5), which captures the state of the processor (i.e., the contents of all its registers) into a structure called **PC\_JumpBuf**. Capturing the processor's context will allow us to return to **PC\_DOSSaveReturn()** and execute the code immediately following the call to **setjmp()**. Because **PC\_ExitFlag** was initialized to **FALSE** L1.6(1), **PC\_DOSSaveReturn()** skips the code in the if statement (i.e. L1.6(6)-(9)) and returns to the caller (i.e. **main()**). When you want to return to DOS, all you have to do is call **PC\_DOSReturn()** (see listing 1.7) which sets **PC\_ExitFlag** to **TRUE** L1.7(1) and execute a **longjmp()** L1.7(2). This brings the processor back in **PC\_DOSSaveReturn()** (just after the call to **setjmp()**) L1.6(5). This time, however, **PC\_ExitFlag** is **TRUE** and the code following the if statement is executed. **PC\_DOSSaveReturn()** changes the tick rate back to 18.2 Hz L1.6(6), restores the PC's tick ISR

handler L1.6(7), clears the screen L1.6(8) and returns to the DOS prompt through the **exit(0)** function L1.6(9).

```
void PC_DOSSaveReturn (void)
{
    PC_ExitFlag = FALSE;                                (1)
    OSTickDOSCtr = 8;                                    (2)
    PC_TickISR = PC_VectGet(VECT_TICK);                  (3)

    OS_ENTER_CRITICAL();
    PC_VectSet(VECT_DOS_CHAIN, PC_TickISR);              (4)
    OS_EXIT_CRITICAL();

    setjmp(PC_JumpBuf);                                  (5)
    if (PC_ExitFlag == TRUE) {
        OS_ENTER_CRITICAL();
        PC_SetTickRate(18);                              (6)
        PC_VectSet(VECT_TICK, PC_TickISR);              (7)
        OS_EXIT_CRITICAL();
        PC_DisPClrScr(DISP_FGND_WHITE + DISP_BGND_BLACK); (8)
        exit(0);                                          (9)
    }
}
```

### Listing 1.6, Saving the DOS environment.

```
void PC_DOSReturn (void)
{
    PC_ExitFlag = TRUE;                                  (1)
    longjmp(PC_JumpBuf, 1);                              (2)
}
```

### Listing 1.7, Setting up to return to DOS.

Now we can go back to **main()** in listing 1.5. **main()** then calls **PC\_VectSet()** L1.5(4) to install  $\mu$  C/OS-II's context switch handler. Task level context switching is done by issuing an 80x86 **INT** instruction to this vector location. I decided to use vector 0x80 (i.e. 128) because it's not used by either DOS or the BIOS.

A binary semaphore is then created L1.5(5) to guard access to the random number generator provided by the Borland C/C++ library. I decided to use a semaphore because I didn't know whether or not this function was reentrant. I assumed it was not. Because I initialized the semaphore to 1, I am indicating that only one task can access the random number generator at any time.

Before starting multitasking, I create one task L1.5(6) called **TaskStart()**. It is very important that you create at least one task before starting multitasking through **OSStart()** L1.5(7). Failure to do this will certainly make your application crash. In fact, you may always want to only create a single task if you

are planning on using the CPU usage statistic task.  $\mu$  C/OS-II's statistic task assumes that no other task is running for a whole second. If, however, you need to create additional tasks before starting multitasking, you must ensure that your task code will monitor the global variable **OSStatRdy** and delay execution (i.e. call **OSTimeDly( )**) until this variable becomes **TRUE**. This indicates that  $\mu$  C/OS-II has collected its data for CPU usage statistics.

### ***1.07.02 Example #1, TaskStart()***

A major portion of the work in example #1 is done by **TaskStart( )**. The pseudo-code for this function is shown in listing 1.8. The task starts by displaying a banner on top of the screen identifying this as example #1 L1.8(1). Next, we disable interrupts to change the tick ISR (Interrupt Service Routine) vector so that it now points to  $\mu$  C/OS-II's tick handler L1.8(2) and, change the tick rate from the default DOS 18.2 Hz to 200 Hz L1.8(3). We sure don't want to be interrupted while in the process of changing an interrupt vector! Note that **main( )** purposely didn't set the interrupt vector to  $\mu$  C/OS-II's tick handler because you don't want a tick interrupt to occur before the operating system is fully initialized and running. If you run code in an embedded application, you should always enable the ticker (as I have done here) from within the first task.



```

    OS_ENTER_CRITICAL();
    OSIdleCtr      = 0L;                                (2)
    OS_EXIT_CRITICAL();
    OTimeDly(OS_TICKS_PER_SEC);                          (3)
    OS_ENTER_CRITICAL();
    OSIdleCtrMax = OSIdleCtr;                             (4)
    OSStatRdy    = TRUE;                                  (5)
    OS_EXIT_CRITICAL();
}

```

### Listing 1.9, Determining the PC's speed.

#### *1.07.03 Example #1, TaskN()*

**OSStatInit()** returns back to **TaskStart()** and we can now create 10 identical tasks (all running the same code) L1.8(5). **TaskStart()** will create all the tasks and no context switch will occur because **TaskStart()** has a priority of 0 (i.e. the highest priority). When all the tasks are created, **TaskStart()** enters the infinite loop portion of the task and continuously displays statistics on the screen, checks to see if the ESCAPE key was pressed and then delay for one second before starting the loop again. If you press the escape key, **TaskStart()** calls **PC\_DOSReturn()** and we gracefully return back to the DOS prompt.

The task code is shown in listing 1.10. When the task gets to execute, it tries to acquire a semaphore L1.10(1) so that we can call the Borland C/C++ library function **random()** L1.10(2). I assumed here that the random function is non-reentrant so, each of the 10 tasks must have exclusive access to this code in order to proceed. We release the semaphore when both X and Y coordinates are obtained L1.10(3). The task displays a number (between '0' and '9') which is passed to the task when it is created L1.10(4). Finally, each task delays itself for one tick L1.10(5) and thus, each task will execute 200 times per second! With the 10 task this means that  $\mu$  C/OS-II will context switch between these tasks 2000 per second.

```

void Task (void *data)
{
    UBYTE x;
    UBYTE y;
    UBYTE err;

    for (;;) {
        OSSemPend(RandomSem, 0, &err);           (1)
        x = random(80);                           (2)
        y = random(16);
        OSSemPost(RandomSem);                     (3)
        PC_Dispatch(x, y + 5, *(char *)data, DISP_FGND_LIGHT_GRAY); (4)
        OSTimeDly(1);                             (5)
    }
}

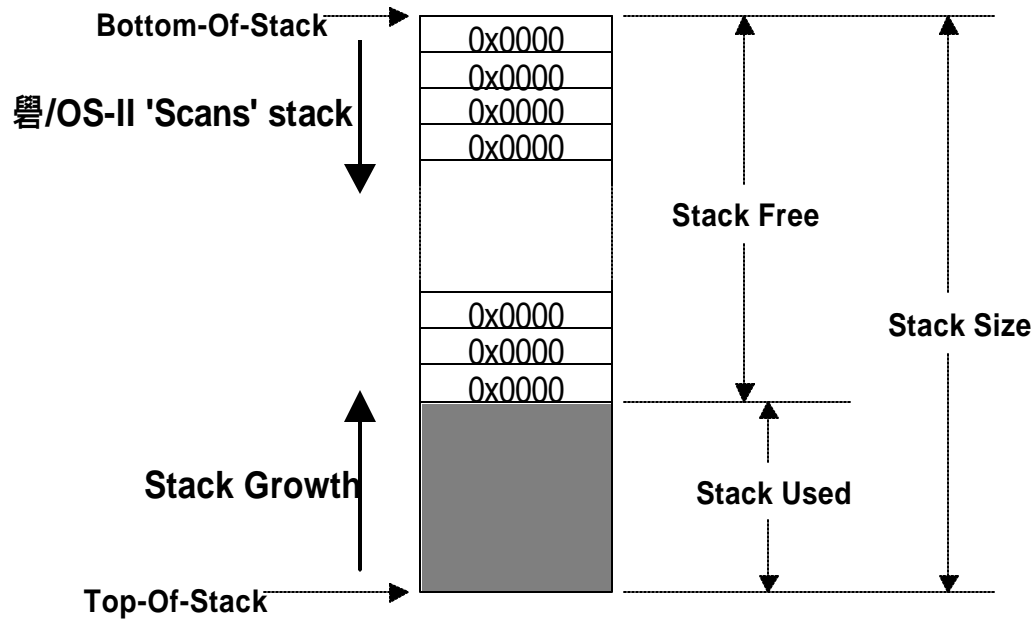
```

**Listing 1.10,  
Task that displays a number at random locations on the screen.**

## ***1.08 Example #2***

Example #2 makes use of the extended task create function and  $\mu$ C/OS-II's stack checking feature. Stack checking is useful when you don't actually know ahead of time how much stack space you need to allocate for each task. In this case, you allocate much more stack space than you think you need and you let  $\mu$ C/OS-II tell you exactly how much stack space is actually used up. You obviously need to run the application long enough and under your worst case conditions to get proper numbers. Your final stack size should accommodate for system expansion so make sure you allocate between 10 and 25% more. In safety critical applications, however, you may even want to consider 100% more. What you should get from stack checking is a 'ballpark' figure; you are not looking for an exact stack usage.

$\mu$ C/OS-II's stack checking function assumes that the stack is initially filled with zeros when the task is created. You accomplish this by telling **OSTaskCreateExt ( )** to clear the stack upon task creation (i.e. you OR both **OS\_TASK\_OPT\_STK\_CHK** and **OS\_TASK\_OPT\_STK\_CLR** for the **opt** argument). If you intend to create and delete tasks, you should set these options so that a new stack is cleared every time the task is created. You should note that having **OSTaskCreateExt ( )** clear the stack increases execution overhead which obviously depends on the stack size.  $\mu$ C/OS-II scans the stack starting at the bottom until it finds a non-zero entry (see figure 1-1). As the stack is scanned,  $\mu$ C/OS-II increments a counter that indicates how many entries are free (Stack Free).



**Figure 1-1  $\mu$  C/OS-II Stack checking**

The second example is found in `\SOFTWARE\uCOS-II\EX2_x86L` and consists of a total of 9 tasks. Again,  $\mu$  C/OS-II creates two 'internal' tasks: the idle task and the task that determines CPU usage. **EX2L.C** creates the other 7 tasks. As with example #1, **TaskStart()** is created by **main()** and its function is to create the other tasks and display the following statistics on the screen:

- 1) the number of task switches in one second,
- 2) the CPU usage in %,
- 3) the number of context switches,
- 4) the current date and time, and
- 5)  $\mu$  C/OS-II's version.

### ***1.08.01 Example #2, main()***

**main()** looks just like the code for example #1 (see listing 1.11) except for two small differences. First, **main()** calls **PC\_ElapsedInit()** L1.11(1) to initialize the elapsed time measurement function which will be used to measure the execution time of **OSTaskStkChk()**. Second, all tasks are created using the extended task create function instead of **OSTaskCreate()** L1.11(2). This allows us, among other things, to perform stack checking on each task. In addition to the same four arguments needed by **OSTaskCreate()**, **OSTaskCreateExt()** requires five additional arguments: a task ID, a pointer to the bottom of the stack, the stack size (in number of elements), a pointer to a user supplied Task Control Block (TCB) extension, and a variable used to specify options to the task. One of the options is used to tell  $\mu$  C/OS-II that stack checking is allowed on the created task. Example #2 doesn't make use of the TCB (Task Control Block) extension pointer.

```
void main (void)
{
    PC_DispcClrScr(DISP_FGND_WHITE + DISP_BGND_BLACK);
    OSInit();
    PC_DOSSaveReturn();
    PC_VectSet(uCOS, OSCtxSw);
    PC_ElapsedInit();                                (1)
    OSTaskCreateExt(TaskStart,                        (2)
                    (void *)0,
                    &TaskStartStk[TASK_STK_SIZE-1],
                    TASK_START_PRIO,
                    TASK_START_ID,
                    &TaskStartStk[0],
                    TASK_STK_SIZE,
                    (void *)0,
                    OS_TASK_OPT_STK_CHK | OS_TASK_OPT_STK_CLR);
    OSStart();
}
```

**Listing 1.11, main() for example #2.**



### ***1.08.02 Example #2, TaskStart()***

Listing 1.12 shows the pseudo code for **TaskStart()**. The first five operations are similar to those found in example #1. **TaskStart()** creates two mailboxes that will be used by Task #4 and Task #5 L1.12(1). A task that will display the current date and time is created as well as five application tasks L1.12(20).

```
void TaskStart (void *data)
{
    Prevent compiler warning by assigning 'data' to itself;
    Display a banner and non-changing text;
    Install uC/OS-II's tick handler;
    Change the tick rate to 200 Hz;
    Initialize the statistics task;
    Create 2 mailboxes which are used by Task #4 and #5;           (1)
    Create a task that will display the date and time on the screen; (2)
    Create 5 application tasks;
    for (;;) {
        Display #tasks running;
        Display CPU usage in %;
        Display #context switches per seconds;
        Clear the context switch counter;
        Display uC/OS-II's version;
        if (Key was pressed) {
            if (Key pressed was the ESCAPE key) {
                Return to DOS;
            }
        }
        Delay for 1 second;
    }
}
```

**Listing 1.12, Pseudo-code for TaskStart().**

### ***1.08.03 Example #2, TaskN()***

The code for **Task1()** checks the size of the stack for each of the seven application tasks. The execution time of **OSTaskStkChk()** is measured L1.13(1)-(2) and displayed along with the stack size information. Note that all stack size data are displayed in number of bytes. This task executes 10 times per second L1.13(3).

```

void Task1 (void *pdata)
{
    INT8U      err;
    OS_STK_DATA data;
    INT16U     time;
    INT8U      i;
    char       s[80];

    pdata = pdata;
    for (;;) {
        for (i = 0; i < 7; i++) {
            PC_ElapsedStart();
            err = OSTaskStkChk(TASK_START_PRIO+i, &data);
            time = PC_ElapsedStop();
            if (err == OS_NO_ERR) {
                sprintf(s, "%3ld      %3ld      %3ld      %5d",
                        data.OSFree + data.OSUsed,
                        data.OSFree,
                        data.OSUsed,
                        time);
                PC_DispatchStr(19, 12+i, s, DISP_FGND_YELLOW);
            }
        }
        OSTimeDlyHMSM(0, 0, 0, 100);
    }
}

```

**Listing 1.13, Example #2, Task #1.**

**Task2 ( )** displays a clockwise rotating wheel on the screen. Each rotation completes in 200 mS (i.e. 4 x 10 ticks x 5 mS/tick).

```

void Task2 (void *data)
{
    data = data;
    for (;;) {
        PC_DispatchChar(70, 15, '|', DISP_FGND_WHITE + DISP_BGND_RED);
        OSTimeDly(10);
        PC_DispatchChar(70, 15, '/', DISP_FGND_WHITE + DISP_BGND_RED);
        OSTimeDly(10);
        PC_DispatchChar(70, 15, '-', DISP_FGND_WHITE + DISP_BGND_RED);
        OSTimeDly(10);
        PC_DispatchChar(70, 15, '\\', DISP_FGND_WHITE + DISP_BGND_RED);
        OSTimeDly(10);
    }
}

```

**Listing 1.14, Rotating wheel task.**

**Task3()** also displays a rotating wheel but, the rotation is in the opposite direction. Also, **Task3()** allocates storage on the stack. I decided to fill the dummy array to show that **OSTaskStkChk()** takes less time to determine stack usage when the stack is close to being fully used up L1.15(1).

```
void Task3 (void *data)
{
    char    dummy[500];
    INT16U  i;

    data = data;
    for (i = 0; i < 499; i++) {                (1)
        dummy[i] = '?';
    }
    for (;;) {
        PC_Dispatch(70, 16, '|', DISP_FGND_WHITE + DISP_BGND_BLUE);
        OSTimeDly(20);
        PC_Dispatch(70, 16, '\\', DISP_FGND_WHITE + DISP_BGND_BLUE);
        OSTimeDly(20);
        PC_Dispatch(70, 16, '-', DISP_FGND_WHITE + DISP_BGND_BLUE);
        OSTimeDly(20);
        PC_Dispatch(70, 16, '/', DISP_FGND_WHITE + DISP_BGND_BLUE);
        OSTimeDly(20);
    }
}
```

### Listing 1.15, Rotating wheel task.

**Task4()** sends a message to **Task5()** and waits for an acknowledgement from **Task5()** L1.16(1). The message sent is simply a pointer to a character. Every time **Task4()** receives an acknowledgement from **Task5()** L1.16(2), **Task4()** increments the ASCII character value before sending the next message L1.16(3). When **Task5()** receives the message L1.17(1) (i.e. the character) it displays the character on the screen L1.17(2) and then waits one second L1.17(3) before acknowledging it to task #4 L1.17(4).

```

void Task4 (void *data)
{
    char    txmsg;
    INT8U   err;

    data = data;
    txmsg = 'A';
    for (;;) {
        while (txmsg <= 'Z') {
            OSMboxPost(TxMbox, (void *)&txmsg);           (1)
            OSMboxPend(AckMbox, 0, &err);                  (2)
            txmsg++;                                       (3)
        }
        txmsg = 'A';
    }
}

```

**Listing 1.16, Task #4 communicates with task #5.**

```

void Task5 (void *data)
{
    char *rxmsg;
    INT8U   err;

    data = data;
    for (;;) {
        rxmsg = (char *)OSMboxPend(TxMbox, 0, &err);      (1)
        PC_DispChar(70, 18, *rxmsg, DISP_FGND_YELLOW+DISP_BGND_RED); (2)
        OSTimeDlyHMSM(0, 0, 1, 0);                        (3)
        OSMboxPost(AckMbox, (void *)1);                   (4)
    }
}

```

**Listing 1.17, Task #5 receives and displays a message.**

**TaskClk( )** (listing 1.18) is a task that displays the current date and time every second.

```

void TaskClk (void *data)
{
    struct time now;
    struct date today;
    char      s[40];

    data = data;
    for (;;) {
        PC_GetDateTime(s);
        PC_DispStr(0, 24, s, DISP_FGND_BLUE + DISP_BGND_CYAN);
        OSTimeDly(OS_TICKS_PER_SEC);
    }
}

```

**Listing 1.18, Clock display task.**

## ***1.09 Example #3***

Example #3 demonstrates some additional features of  $\mu$ C/OS-II. Specifically, example #3 uses the TCB (Task Control Block) extension capability of **OSTaskCreateExt()**, the user defined context switch hook (**OSTaskSwHook()**), the user defined statistic task hook (**OSTaskStatHook()**), and message queues.

The third example is found in **\SOFTWARE\uCOS-II\EX3\_x86L** and again, consists of a total of 9 tasks.  $\mu$ C/OS-II creates two ‘internal’ tasks: the idle task and the task that determines CPU usage. **EX3L.C** creates the other 7 tasks. As with examples #1 and #2, **TaskStart()** is created by **main()** and its function is to create the other tasks and display statistics on the screen.

### ***1.09.01 Example #3, main()***

**main()** (see listing 1.19) looks just like the code for example #2 except that the task is given a name which is saved in a user defined TCB extension L1.19(1) (the declaration for the extension is found in **INCLUDES.H** and shown in listing 1.20). I decided to allocate 30 characters for the task name (including the NUL character) to show that you can have fairly descriptive task names L1.20(1). I disabled stack checking for **TaskStart()** because we will not be using that feature in this example L1.19(2).

```

void main (void)
{
    PC_DispcClrScr(DISP_FGND_WHITE + DISP_BGND_BLACK);
    OSInit();
    PC_DOSSaveReturn();
    PC_VectSet(uCOS, OSCtxSw);
    PC_ElapsedInit();

    strcpy(TaskUserData[TASK_START_ID].TaskName, "StartTask");      (1)
    OSTaskCreateExt(TaskStart,
                    (void *)0,
                    &TaskStartStk[TASK_STK_SIZE-1],
                    TASK_START_PRIO,
                    TASK_START_ID,
                    &TaskStartStk[0],
                    TASK_STK_SIZE,
                    &TaskUserData[TASK_START_ID],
                    0);                                              (2)

    OSStart();
}

```

**Listing 1.19, main() for example #3.**

```

typedef struct {
    char    TaskName[30];      (1)
    INT16U  TaskCtr;
    INT16U  TaskExecTime;
    INT32U  TaskTotExecTime;
} TASK_USER_DATA;

```

**Listing 1.20, TCB extension data structure.**

### ***1.09.02 Example #3, Tasks***

The pseudo code for **TaskStart()** is shown in listing 1.21. The code hasn't changed much from example #2 except for three things:

- 1) A message queue is created L1.21(1) for use by **Task1()**, **Task2()** and **Task3()**,
- 2) Each task has a name which is stored in the TCB extension L1.21(2) and,
- 3) Stack checking will not be allowed.

```

void TaskStart (void *data)
{
    Prevent compiler warning by assigning 'data' to itself;
    Display a banner and non-changing text;
    Install uC/OS-II's tick handler;
    Change the tick rate to 200 Hz;
    Initialize the statistics task;
    Create a message queue;                                     (1)
    Create a task that will display the date and time on the screen;
    Create 5 application tasks with a name stored in the TCB ext.; (2)
    for (;;) {
        Display #tasks running;
        Display CPU usage in %;
        Display #context switches per seconds;
        Clear the context switch counter;
        Display uC/OS-II's version;
        if (Key was pressed) {
            if (Key pressed was the ESCAPE key) {
                Return to DOS;
            }
        }
        Delay for 1 second;
    }
}

```

### Listing 1.21, Pseudo-code for TaskStart() for example #3.

**Task1()** writes messages into the message queue L1.22(1). **Task1()** delays itself whenever a message is sent L1.22(2). This allows the receiver to display the message at a humanly readable rate. Three different messages are sent.

```

void Task1 (void *data)
{
    char one   = '1';
    char two   = '2';
    char three = '3';

    data = data;
    for (;;) {
        OSQPost(MsgQueue, (void *)&one);           (1)
        OSTimeDlyHMSM(0, 0, 1, 0);                 (2)
        OSQPost(MsgQueue, (void *)&two);
        OSTimeDlyHMSM(0, 0, 0, 500);
        OSQPost(MsgQueue, (void *)&three);
        OSTimeDlyHMSM(0, 0, 1, 0);
    }
}

```

### Listing 1.22, Example #3, Task #1.

**Task2()** pends on the message queue with no timeout L1.23(1). This means that the task will wait forever for a message to arrive. When the message is received, **Task2()** displays the message on the screen L1.23(2) and delays itself for 500 mS L1.23(3). This will allow **Task3()** to receive a message because **Task2()** will not be checking the queue for a whole 500 mS.

```
void Task2 (void *data)
{
    INT8U *msg;
    INT8U err;

    data = data;
    for (;;) {
        msg = (INT8U *)OSQPend(MsgQueue, 0, &err);           (1)
        PC_Dispatch(70, 14, *msg, DISP_FGND_YELLOW+DISP_BGND_BLUE); (2)
        OSTimeDlyHMSM(0, 0, 0, 500);                          (3)
    }
}
```

### Listing 1.23, Example #3, Task #2.

**Task3()** also pends on the message queue but, it is willing to wait for only 250 mS L1.24(1). If a message is received, **Task3()** will display the message number L1.24(3). If a timeout occurs, **Task3()** will display a 'T' (for timeout) instead L1.24(2).

```
void Task3 (void *data)
{
    INT8U *msg;
    INT8U err;

    data = data;
    for (;;) {
        msg = (INT8U *)OSQPend(MsgQueue, OS_TICKS_PER_SEC/4, &err); (1)
        if (err == OS_TIMEOUT) {
            PC_Dispatch(70,15, 'T', DISP_FGND_YELLOW+DISP_BGND_RED); (2)
        } else {
            PC_Dispatch(70,15, *msg, DISP_FGND_YELLOW+DISP_BGND_BLUE); (3)
        }
    }
}
```

### Listing 1.24, Example #3, Task #3.

**Task4()** doesn't do much except post L1.25(1) and pend L1.25(2) on a mailbox. This basically allows you to measure the time it takes for these calls to execute on your particular PC. **Task4()** executes every 10 mS L1.25(3).

```
void Task4 (void *data)
```



```

{
    OS_EVENT *mbox;
    INT8U     err;

    data = data;
    mbox = OSMboxCreate((void *)0);
    for (;;) {
        OSMboxPost(mbox, (void *)1);           (1)
        OSMboxPend(mbox, 0, &err);             (2)
        OSTimeDlyHMSM(0, 0, 0, 10);           (3)
    }
}

```

### Listing 1.25, Example #3, Task #4.

**Task5 ( )** does nothing useful except it delays itself for 1 clock tick L1.26(1). Note that all  $\mu$  C/OS-II tasks MUST call a service provided by  $\mu$  C/OS-II to wait for either time to expire or an event to occur. If this is not done, the task would prevent all lower priority tasks from running.

```

void Task5 (void *data)
{
    data = data;
    for (;;) {
        OSTimeDly(1);           (1)
    }
}

```

### Listing 1.26, Example #3, Task #5.

**TaskClk ( )** is a task that displays the current date and time every second.

### 1.09.03 Example #3, Notes

There are things happening behind the scenes and would not be apparent just by looking at **EX3L.C**. **EX3L.C** contains code for **OSTaskSwHook ( )** that measures the execution time of each task, how often each task executes, and keeps track of total execution time of each task. This information is stored in the TCB extension so that it can be displayed. **OSTaskSwHook ( )** is called every time a context switch occurs.

The execution time of the task being switched out is obtained by reading a timer on the PC through the function **PC\_ElapsedStop ( )** L1.27(1). It is assumed that the timer was started by calling **PC\_ElapsedStart ( )** when the task was switched in L1.27(2). The first context switch will probably read an incorrect value but this is not critical. **OSTaskSwHook ( )** then retrieves the pointer to the TCB extension L1.27(3) and, if an extension exist L1.27(4) for the task, a counter is incremented L1.27(5) which indicates how often the current task has been switched out. Such a counter is useful to determine if a particular task is running. Next, the execution time of the task being switched out is saved in the TCB extension L1.27(6). A separate accumulator is used to maintain the total execution time L1.27(7). This allows you to determine the percentage of time each task takes with respect to other tasks in an application. Note that these statistics are displayed by **OSTaskStatHook ( )**.

```
void OSTaskSwHook (void)
{
    INT16U          time;
    TASK_USER_DATA *puser;

    time = PC_ElapsedStop();           (1)
    PC_ElapsedStart();                 (2)
    puser = OSTCBCur->OSTCBExtPtr;     (3)
    if (puser != (void *)0) {         (4)
        puser->TaskCtr++;              (5)
        puser->TaskExecTime = time;    (6)
        puser->TaskTotExecTime += time; (7)
    }
}
```

#### Listing 1.27, User defined OSTaskSwHook().

μC/OS-II always calls a function called **OSTaskStatHook ( )** when you enable the statistic task (i.e. the configuration constant **OS\_TASK\_STAT\_EN** in **OS\_CFG.H** is set to 1). When enabled, the statistic task **OSTaskStat ( )** always calls the user definable function **OSTaskStatHook ( )**. This happens every second. I decided to have **OSTaskStatHook ( )** display the statistics collected by **OSTaskSwHook ( )**. In addition, **OSTaskStatHook ( )** also computes the percentage of time that each task takes with respect to each other.

The total execution time of all tasks is computed in L1.28(1). Then, individual statistics are displayed at the proper location on the screen L1.28(2) by a function (i.e. **DispTaskStat()**) that takes care of converting the values into ASCII. Next, the percentage of execution time is computed for each task L1.28(3) and displayed L1.28(4).

```
void OSTaskStatHook (void)
{
    char    s[80];
    INT8U   i;
    INT32U  total;
    INT8U   pct;

    total = 0L;
    for (i = 0; i < 7; i++) {
        total += TaskUserData[i].TaskTotExecTime;           (1)
        DispTaskStat(i);                                   (2)
    }
    if (total > 0) {
        for (i = 0; i < 7; i++) {
            pct = 100 * TaskUserData[i].TaskTotExecTime / total; (3)
            sprintf(s, "%3d %%", pct);
            PC_DisPStr(62, i + 11, s, DISP_FGND_YELLOW);      (4)
        }
    }
    if (total > 1000000000L) {
        for (i = 0; i < 7; i++) {
            TaskUserData[i].TaskTotExecTime = 0L;
        }
    }
}
```

**Listing 1.28, User defined OSTaskStatHook().**

## Chapter 2

# *Real-Time Systems Concepts*

Real-time systems are characterized by the fact that severe consequences will result if logical as well as timing correctness properties of the system are not met. There are two types of real-time systems: SOFT and HARD. In a SOFT real-time system, tasks are performed by the system as fast as possible, but the tasks don't have to finish by specific times. In HARD real-time systems, tasks have to be performed not only correctly but on time. Most real-time systems have a combination of SOFT and HARD requirements. Real-time applications cover a wide range. Most applications for real-time systems are *embedded*. This means that the computer is built into a system and is not seen by the user as being a computer. Examples of embedded systems are:

Process control:

- Food processing
- Chemical plants

Automotive:

- Engine controls
- Anti-lock braking systems

Office automation:

- FAX machines
- Copiers

Computer peripherals:

- Printers
- Terminals
- Scanners
- Modems

Robots

Aerospace:

- Flight management systems
- Weapons systems
- Jet engine controls

Domestic:

- Microwave ovens
- Dishwashers
- Washing machines
- Thermostats

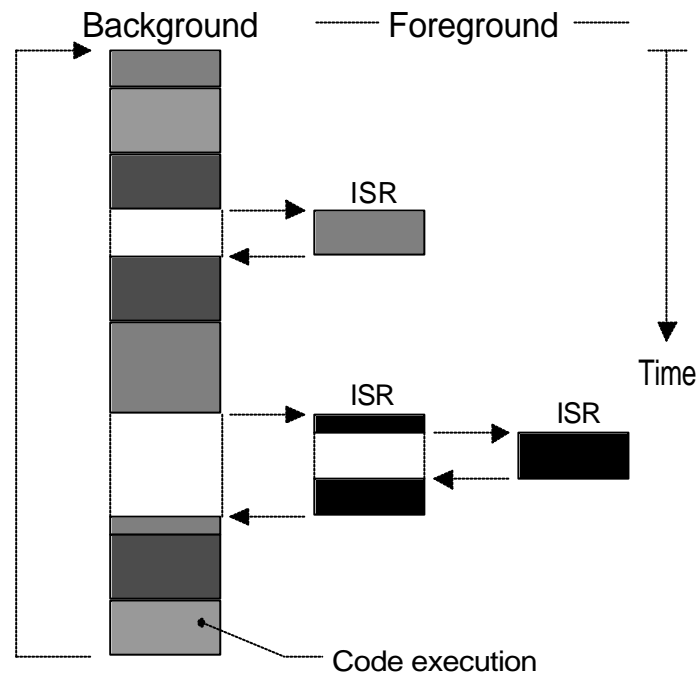
Real-time software applications are typically more difficult to design than non-real-time applications. This chapter describes real-time concepts.

### ***2.00 Foreground/Background Systems***

Small systems of low complexity are generally designed as shown in Figure 2-1. These systems are called *foreground/background* or *super-loops*. An application consists of an infinite loop that calls modules (that is, functions) to perform the desired operations (background). Interrupt Service Routines (ISRs) handle asynchronous events (foreground). Foreground is also called *interrupt level* while background is called *task level*. Critical operations must be performed by the ISRs to ensure that they are dealt with in a timely fashion. Because of this, ISRs have a

tendency to take longer than they should. Also, information for a background module made available by an ISR is not processed until the background routine gets its turn to execute. This is called the *task level response*. The worst case task level response time depends on how long the background loop takes to execute. Because the execution time of typical code is not constant, the time for successive passes through a portion of the loop is non-deterministic. Furthermore, if a code change is made, the timing of the loop is affected.

Most high volume microcontroller-based applications (e.g., microwave ovens, telephones, toys, and so on) are designed as foreground/background systems. Also, in microcontroller-based applications, it may be better (from a power consumption point of view) to halt the processor and perform all of the processing in ISRs.



**Figure 2-1, Foreground/background systems**

### 2.01 Critical Section of Code

A critical section of code, also called a *critical region*, is code that needs to be treated indivisibly. Once the section of code starts executing, it must not be interrupted. To ensure this, interrupts are typically disabled before the critical code is executed and enabled when the critical code is finished (see also Shared Resource).

### 2.02 Resource

A resource is any entity used by a task. A resource can thus be an I/O device such as a printer, a keyboard, a display, etc. or a variable, a structure, an array, etc.

### 2.03 Shared Resource

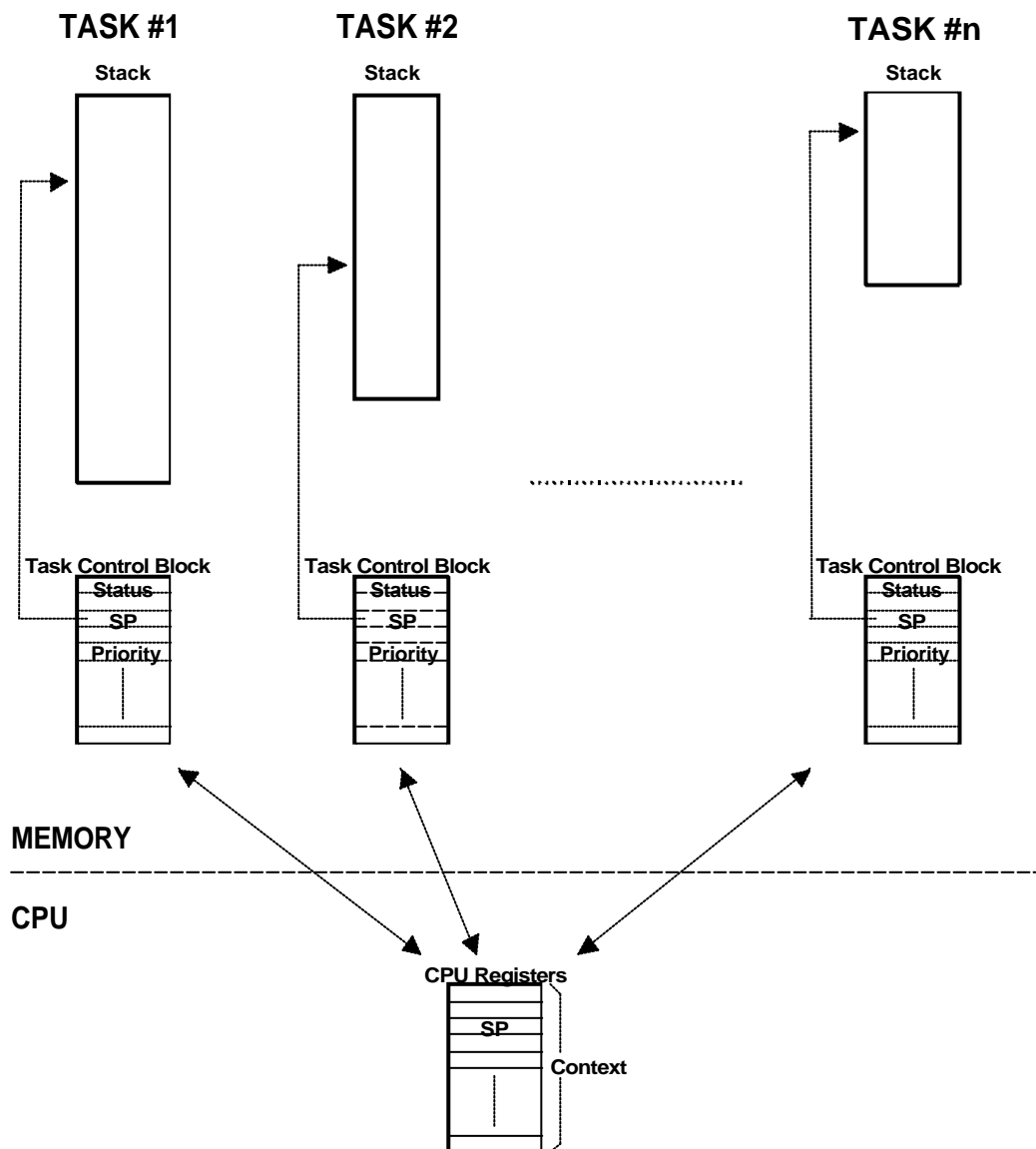
A shared resource is a resource that can be used by more than one task. Each task should gain exclusive access to the shared resource to prevent data corruption. This is called *Mutual Exclusion* and techniques to ensure mutual exclusion are discussed in section 2.19, *Mutual Exclusion*.

### 2.04 Multitasking

Multitasking is the process of scheduling and switching the CPU (Central Processing Unit) between several tasks; a single CPU switches its attention between several sequential tasks. Multitasking is like foreground/background with multiple backgrounds. Multitasking maximizes the utilization of the CPU and also provides for modular construction of applications. One of the most important aspects of multitasking is that it allows the application programmer to manage complexity inherent in real-time applications. Application programs are typically easier to design and maintain if multitasking is used.

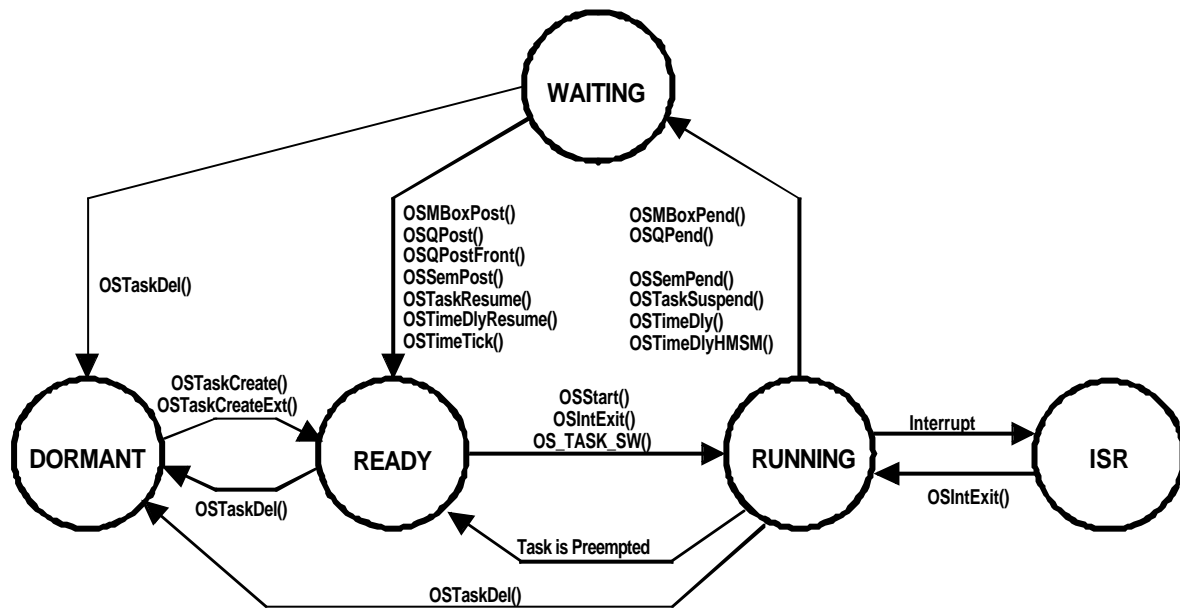
## 2.05 Task

A task, also called a *thread*, is a simple program that thinks it has the CPU all to itself. The design process for a real-time application involves splitting the work to be done into tasks which are responsible for a portion of the problem. Each task is assigned a priority, its own set of CPU registers, and its own stack area (as shown in Figure 2-2).



**Figure 2-2, Multiple tasks.**

Each task typically is an infinite loop that can be in any one of five states: *DORMANT*, *READY*, *RUNNING*, *WAITING FOR AN EVENT*, or *INTERRUPTED* (see Figure 2-3). The *DORMANT* state corresponds to a task which resides in memory but has not been made available to the multitasking kernel. A task is *READY* when it can execute but its priority is less than the currently running task. A task is *RUNNING* when it has control of the CPU. A task is *WAITING FOR AN EVENT* when it requires the occurrence of an event (waiting for an I/O operation to complete, a shared resource to be available, a timing pulse to occur, time to expire etc.). Finally, a task is *INTERRUPTED* when an interrupt has occurred and the CPU is in the process of servicing the interrupt. Figure 2-3 also shows the functions provided by  $\mu$ COS-II to make a task switch from one state to another.



**Figure 2-3, Task states**

## 2.06 Context Switch (or Task Switch)

When a multitasking kernel decides to run a different task, it simply saves the current task's *context* (CPU registers) in the current task's context storage area – its stack (see Figure 2-2). Once this operation is performed, the new task's context is restored from its storage area and then resumes execution of the new task's code. This process is called a *context switch* or a *task switch*. Context switching adds overhead to the application. The more registers a CPU has, the higher the overhead. The time required to perform a context switch is determined by how many registers have to be saved and restored by the CPU. Performance of a real-time kernel should not be judged on how many context switches the kernel is capable of doing per second.

## 2.07 Kernel

The kernel is the part of a multitasking system responsible for the management of tasks (that is, for managing the CPU's time) and communication between tasks. The fundamental service provided by the kernel is context switching. The use of a real-time kernel will generally simplify the design of systems by allowing the application to be divided into multiple tasks managed by the kernel. A kernel will add overhead to your system because it requires extra ROM (code space), additional RAM for the kernel data structures but most importantly, each task requires its own stack space which has a tendency to eat up RAM quite quickly. A kernel will also consume CPU time (typically between 2 and 5%).

Single chip microcontrollers are generally not able to run a real-time kernel because they have very little RAM.

A kernel can allow you to make better use of your CPU by providing you with indispensable services such as semaphore management, mailboxes, queues, time delays, etc. Once you design a system using a real-time kernel, you will not want to go back to a foreground/background system.

## **2.08 Scheduler**

The scheduler, also called the *dispatcher*, is the part of the kernel responsible for determining which task will run next. Most real-time kernels are priority based. Each task is assigned a priority based on its importance. The priority for each task is application specific. In a priority-based kernel, control of the CPU will always be given to the highest priority task ready-to-run. When the highest-priority task gets the CPU, however, is determined by the type of kernel used. There are two types of priority-based kernels: *non-preemptive* and *preemptive*.

## **2.09 Non-Preemptive Kernel**

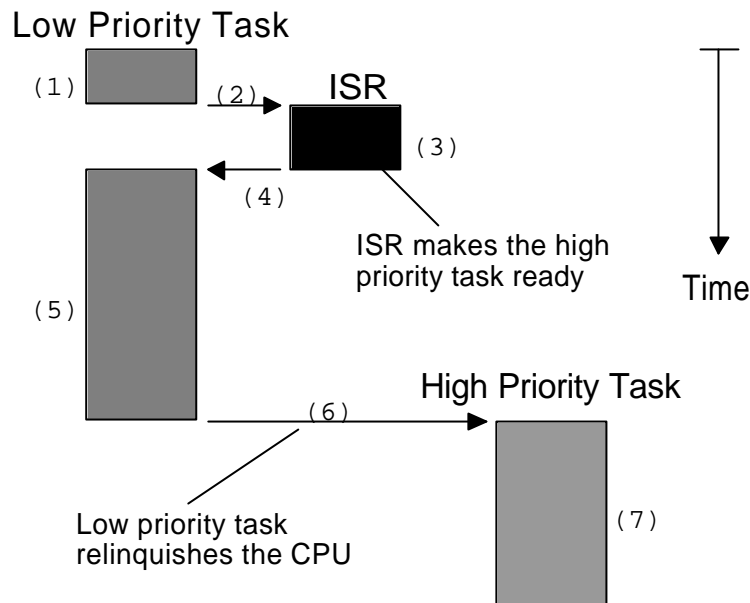
Non-preemptive kernels require that each task does something to explicitly give up control of the CPU. To maintain the illusion of concurrency, this process must be done frequently. Non-preemptive scheduling is also called *cooperative multitasking*; tasks cooperate with each other to share the CPU. Asynchronous events are still handled by ISRs. An ISR can make a higher priority task ready to run, but the ISR always returns to the interrupted task. The new higher priority task will gain control of the CPU only when the current task gives up the CPU.

One of the advantages of a non-preemptive kernel is that interrupt latency is typically low (see the later discussion on interrupts). At the task level, non-preemptive kernels can also use non-reentrant functions (discussed later). Non-reentrant functions can be used by each task without fear of corruption by another task. This is because each task can run to completion before it relinquishes the CPU. Non-reentrant functions, however, should not be allowed to give up control of the CPU.

Task-level response using a non-preemptive kernel can be much lower than with foreground/background systems because task-level response is now given by the time of the longest task.

Another advantage of non-preemptive kernels is the lesser need to guard shared data through the use of semaphores. Each task owns the CPU and you don't have to fear that a task will be preempted. This is not an absolute rule, and in some instances, semaphores should still be used. Shared I/O devices may still require the use of mutual exclusion semaphores; for example, a task might still need exclusive access to a printer.





**Figure 2-4, Non-preemptive kernel**

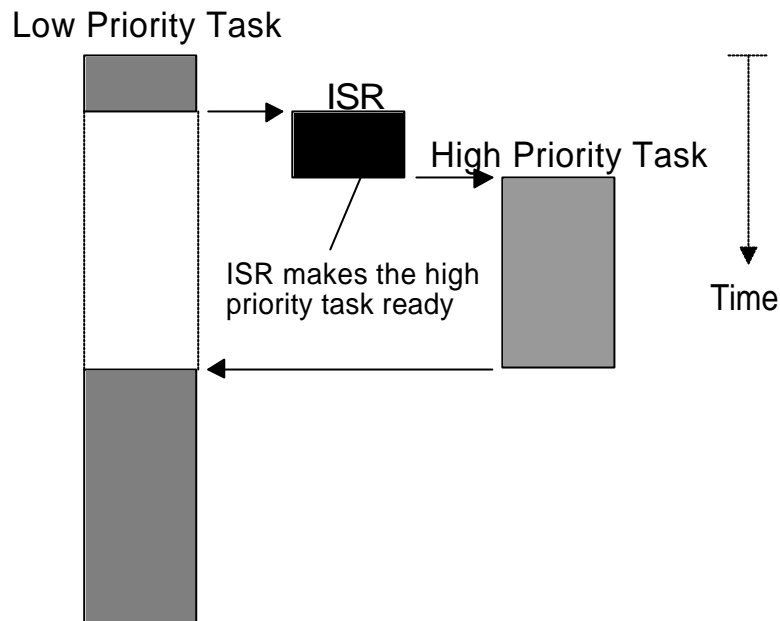
The execution profile of a non-preemptive kernel is shown in Figure 24. A task is executing F2-4(1) but gets interrupted. If interrupts are enabled, the CPU vectors (i.e. jumps) to the ISR F2-4(2). The ISR handles the event F2-4(3) and makes a higher priority task ready-to-run. Upon completion of the ISR, a *Return From Interrupt* instruction is executed and the CPU returns to the interrupted task F2-4(4). The task code resumes at the instruction following the interrupted instruction F2-4(5). When the task code completes, it calls a service provided by the kernel to relinquish the CPU to another task F2-4(6). The new higher priority task then executes to handle the event signaled by the ISR F2-4(7).

The most important drawback of a non-preemptive kernel is responsiveness. A higher priority task that has been made ready to run may have to wait a long time to run, because the current task must give up the CPU when it is ready to do so. As with background execution in foreground/background systems, task-level response time in a non-preemptive kernel is non-deterministic; you never really know when the highest priority task will get control of the CPU. It is up to your application to relinquish control of the CPU.

To summarize, a non-preemptive kernel allows each task to run until it voluntarily gives up control of the CPU. An interrupt will preempt a task. Upon completion of the ISR, the ISR will return to the interrupted task. Task-level response is much better than with a foreground/background system but is still non-deterministic. Very few commercial kernels are non-preemptive.

## 2.10 Preemptive Kernel

A preemptive kernel is used when system responsiveness is important. Because of this,  $\mu$ C/OS-II and most commercial real-time kernels are preemptive. The highest priority task ready to run is always given control of the CPU. When a task makes a higher priority task ready to run, the current task is preempted (suspended) and the higher priority task is **immediately** given control of the CPU. If an ISR makes a higher priority task ready, when the ISR completes, the interrupted task is suspended and the new higher priority task is resumed. This is illustrated in Figure 2-5.



**Figure 2-5, Preemptive kernel**

With a preemptive kernel, execution of the highest priority task is deterministic; you can determine when the highest priority task will get control of the CPU. Task-level response time is thus minimized by using a preemptive kernel.

Application code using a preemptive kernel should not make use of non-reentrant functions unless exclusive access to these functions is ensured through the use of mutual exclusion semaphores, because both a low priority task and a high priority task can make use of a common function. Corruption of data may occur if the higher priority task preempts a lower priority task that is making use of the function.

To summarize, a preemptive kernel always executes the highest priority task that is ready to run. An interrupt will preempt a task. Upon completion of an ISR, the kernel will resume execution to the highest priority task ready to run (not the interrupted task). Task-level response is optimum and deterministic.  $\mu$  C/OS-II is a preemptive kernel.

## 2.11 Reentrancy

A *reentrant function* is a function that can be used by more than one task without fear of data corruption. A reentrant function can be interrupted at any time and resumed at a later time without loss of data. Reentrant functions either use local variables (i.e., CPU registers or variables on the stack) or protect data when global variables are used. An example of a reentrant function is shown in listing 2.1.

```
void strcpy(char *dest, char *src)
{
    while (*dest++ = *src++) {
        ;
    }
    *dest = NUL;
}
```

**Listing 2.1, Reentrant function**

Because copies of the arguments to `strcpy()` are placed on the task's stack, `strcpy()` can be invoked by multiple tasks without fear that the tasks will corrupt each other's pointers.

An example of a non-reentrant function is shown in listing 2.2. `swap()` is a simple function that swaps the contents of its two arguments. For sake of discussion, I assumed that you are using a preemptive kernel, that interrupts are enabled and that `Temp` is declared as a global integer:

```
int Temp;

void swap(int *x, int *y)
{
    Temp = *x;
    *x   = *y;
    *y   = Temp;
}
```

## Listing 2.2, Non-Reentrant function

The programmer intended to make `swap()` usable by any task. Figure 2-6 shows what could happen if a low priority task is interrupted while `swap()` F2-6(1) is executing. Note that at this point `Temp` contains 1. The ISR makes the higher priority task ready to run, and thus, at the completion of the ISR F2-6(2), the kernel (assuming  $\mu$  C/OS-II) is invoked to switch to this task F2-6(3). The high priority task sets `Temp` to 3 and swaps the contents of its variables correctly (that is, `z` is 4 and `t` is 3). The high priority task eventually relinquishes control to the low priority task F2-6(4) by calling a kernel service to delay itself for 1 clock tick (described later). The lower priority task is thus resumed F2-6(5). Note that at this point, `Temp` is still set to 3! When the low-priority task resumes execution, it sets `y` to 3 instead of 1.

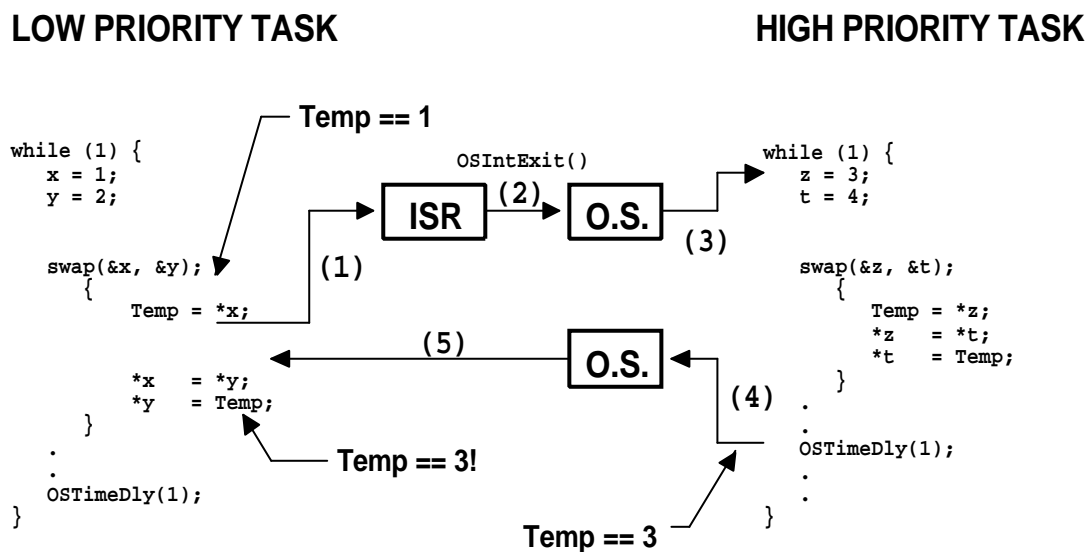


Figure 2-6, Non-reentrant function.

Note that this is a simple example and it is obvious how to make the code reentrant. However, other situations are not as easy to solve. An error caused by a non-reentrant function may not show up in your application during the testing phase; it will most likely occur once the product has been delivered! If you are new to multitasking, you will need to be careful when using non-reentrant functions.

We can make `swap()` reentrant by using one of the following techniques:

- a) Declare **Temp** local to **swap( )**.
- b) Disable interrupts before the operation and enable them after.
- c) Use a semaphore (described later).

If the interrupt occurs either before or after **swap( )**, the **x** and **y** values for both tasks will be correct.

## 2.12 Round Robin Scheduling

When two or more tasks have the same priority, the kernel will allow one task to run for a predetermined amount of time, called *aquantum*, and then selects another task. This is also called *time slicing*. The kernel gives control to the next task in line if:

- a) the current task doesn't have any work to do during its time slice or
- b) the current task completes before the end of its time slice.

μC/OS-II does not currently support round-robin scheduling. Each task must have a unique priority in your application.

## 2.13 Task Priority

A priority is assigned to each task. The more important the task, the higher the priority given to it.

## 2.14 Static Priorities

Task priorities are said to be *static* when the priority of each task does not change during the application's execution. Each task is thus given a fixed priority at compile time. All the tasks and their timing constraints are known at compile time in a system where priorities are static.

## 2.15 Dynamic Priorities

Task priorities are said to be dynamic if the priority of tasks can be changed during the application's execution; each task can change its priority at run-time. This is a desirable feature to have in a real-time kernel to avoid priority inversions.

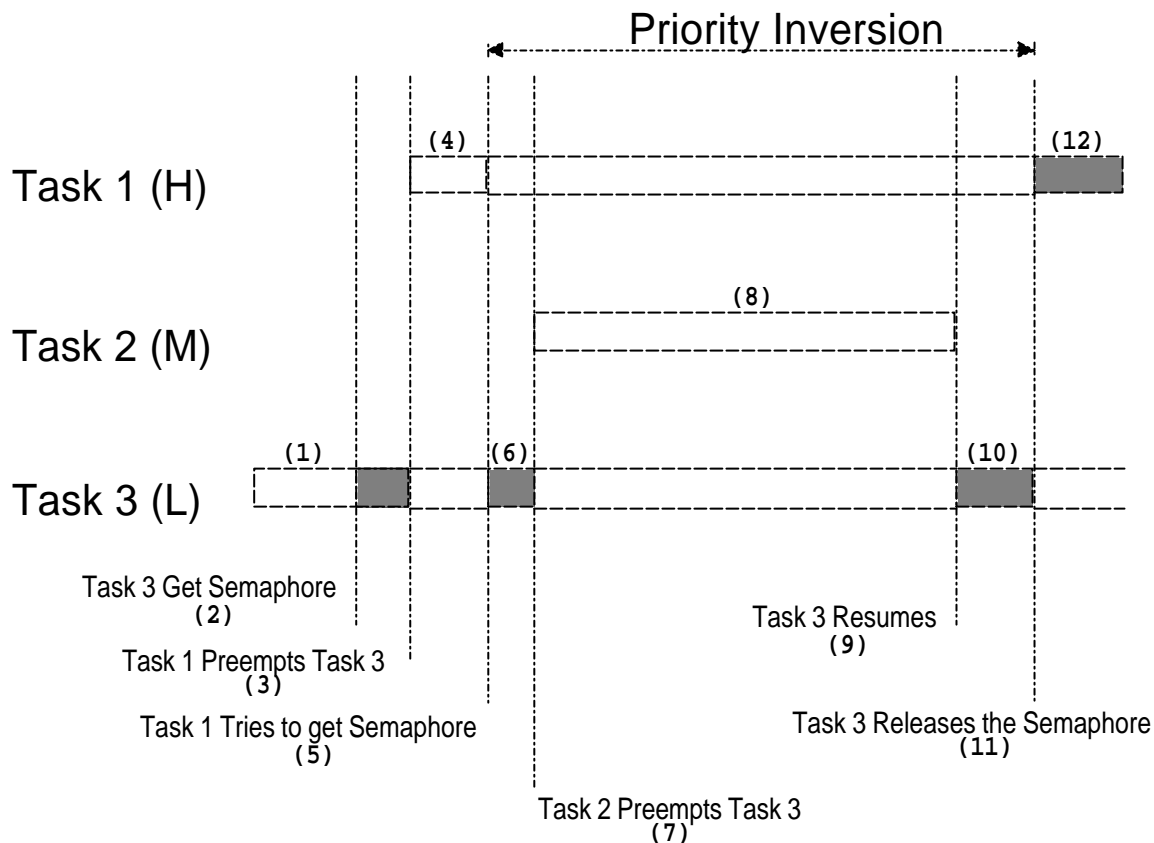
## 2.16 Priority Inversions

Priority inversion is a problem in realtime systems and occurs mostly when you use a real-time kernel. Figure 2-7 illustrates a priority inversion scenario. Task#1 has a higher priority than Task#2 which in turn has a higher priority than Task#3. Task#1 and Task#2 are both waiting for an event to occur and thus, Task#3 is executing F2-7(1). At some point, Task#3 acquires a semaphore (see section 2.18, *Semaphores*) that it needs before it can access a shared resource F2-7(2). Task#3 performs some operations on the acquired resource F2-7(3) until it gets preempted by the high priority task, Task#1 F2-7(4). Task#1 executes for a while until it also wants to access the resource F2-7(5). Because Task#3 owns the resource, Task#1 will have to wait until Task#3 releases the semaphore. As Task#1 tries to get the semaphore, the kernel notices that the semaphore is already owned and thus, Task#1 gets suspended and Task#3 is resumed F2-7(6). Task#3 continues execution until it gets preempted by Task#2 because the event that Task#2 was waiting for occurred F2-7(7). Task #2 handles the event F2-7(8) and when it's done, Task#2 relinquishes the CPU back to Task#3 F2-7(9). Task#3 finishes working with the resource F2-7(10) and thus, releases the semaphore F2-7(11). At this point, the kernel knows that a higher priority task is waiting for the semaphore and, a context switch is done to resume Task#1. At this point, Task#1 has the semaphore and can thus access the shared resource F2-7(12).

The priority of Task#1 has been virtually reduced to that of Task#3's because it was waiting for the resource that Task#3 owned. The situation got aggravated when Task#2 preempted Task#3 which further delayed the execution of Task#1.

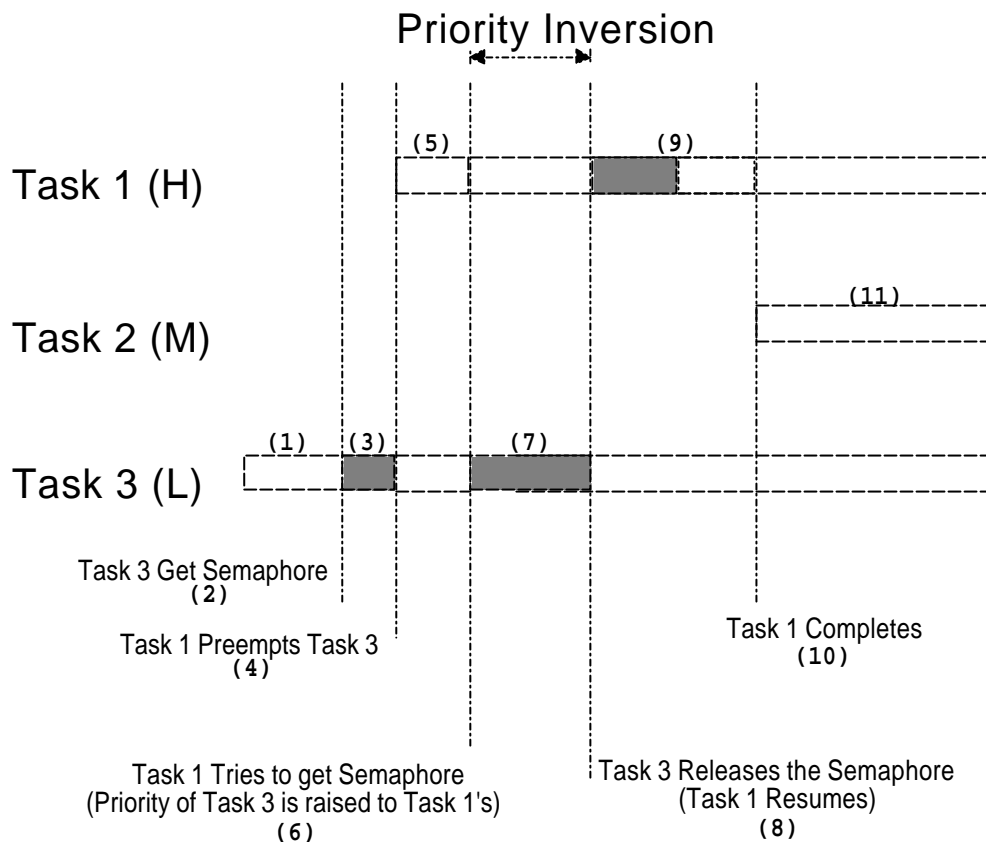
You can correct this situation by raising the priority of Task#3 (above the priority of the other tasks competing for the resource) for the time Task#3 is accessing the resource and restore the original priority level when the task is finished.

A multitasking kernel should allow task priorities to change dynamically to help prevent priority inversions. It takes, however, some time to change a task's priority. What if Task#3 had completed access of the resource before it got preempted by Task#1 and then by Task#2? Had we raised the priority of Task#3 before accessing the resource and then lowered it back when done, we would have wasted valuable CPU time. What is really needed to avoid priority inversion is a kernel that changes the priority of a task automatically. This is called *priority inheritance*, and unfortunately  $\mu$ C/OS-II doesn't support this feature. There are, however, some commercial kernels that do.



**Figure 2-7, Priority inversion problem.**

Figure 2-8 illustrates what happens when a kernel supports priority inheritance. As with the previous example, Task#3 is running F2-8(1) and then acquires a semaphore to access a shared resource F2-8(2). Task#3 accesses the resource F2-8(3) and then gets preempted by Task#1 F2-8(4). Task#1 executes F2-8(5) and then tries to obtain the semaphore F2-8(6). The kernel sees that Task#3 has the semaphore but has a lower priority than Task#1. In this case, the kernel raises the priority of Task#3 to the same level as Task#1. The kernel then switches back to Task#3 so that this task can continue with the resource F2-8(7). When Task#3 is done with the resource, it releases the semaphore F2-8(8). At this point, the kernel reduces the priority of Task#3 to its original value and gives the semaphore to Task#1 which is now free to continue F2-8(9). When Task#1 is done executing F2-8(10), the medium priority task (i.e. Task#2) gets the CPU F2-8(11). Note that Task#2 could have been ready-to-run anytime between F2-8(3) and F2-8(10) without affecting the outcome. There is still some level of priority inversion but, this really cannot be avoided.



**Figure 2-8, Kernel that supports priority inheritance.**

## 2.17 Assigning Task Priorities

Assigning task priorities is not a trivial undertaking because of the complex nature of real-time systems. In most systems, not all tasks are considered critical. Non-critical tasks should obviously be given low priorities. Most real-time systems have a combination of SOFT and HARD requirements. In a SOFT real-time system, tasks are performed by the system as quickly as possible, but they don't have to finish by specific times. In HARD real-time systems, tasks have to be performed not only correctly but on time.

An interesting technique called *Rate Monotonic Scheduling* (RMS) has been established to assign task priorities based on how often tasks execute. Simply put, tasks with the highest rate of execution are given the highest priority (see Figure 2-9).

RMS makes a number of assumptions:

1. All tasks are periodic (they occur at regular intervals).
2. Tasks do not synchronize with one another, share resources, or exchange data.
3. The CPU must always execute the highest priority task that is ready to run. In other words, preemptive scheduling must be used.

Given a set of  $n$  tasks that are assigned RMS priorities, the basic RMS theorem states that all task HARD real-time deadlines will always be met if the following inequality is verified:

$$\sum_i \frac{E_i}{T_i} \leq n \times \left( 2^{\frac{1}{n}} - 1 \right)$$

## Equation 2.1

where,  $E_i$  corresponds to the maximum execution time of task  $i$  and  $T_i$  corresponds to the execution period of task  $i$ . In other words,  $E_i/T_i$  corresponds to the fraction of CPU time required to execute task  $i$ . Table 2.1 shows the value for size  $n(2^{1/n}-1)$  based on the number of tasks. The upper bound for an infinite number of tasks is given by  $\ln(2)$  or 0.693. This means that to meet all HARD real-time deadlines based on RMS, CPU utilization of all time-critical tasks should be less than 70 percent! Note that you can still have non-time-critical tasks in a system and thus use 100 percent of the CPU's time. Using 100 percent of your CPU's time is not a desirable goal because it does not allow for code changes and added features. As a rule of thumb, you should always design a system to use less than 60 to 70 percent of your CPU.

Number of Tasks	$n(2^{1/n}-1)$
1	1.000
2	0.828
3	0.779
4	0.756
5	0.743
.	.
.	.
.	.
Infinity	0.693

**Table 2.1**

RMS says that the highest-rate task has the highest priority. In some cases, the highest-rate task may not be the most important task. Your application will thus dictate how you need to assign priorities. RMS is, however, an interesting starting point.

### 2.19 Mutual Exclusion

The easiest way for tasks to communicate with each other is through shared data structures. This is especially easy when all the tasks exist in a single address space. Tasks can thus reference global variables, pointers, buffers, linked lists, ring buffers, etc. While sharing data simplifies the exchange of information, you must ensure that each task has exclusive access to the data to avoid contention and data corruption. The most common methods to obtain exclusive access to shared resources are:

- a) Disabling interrupts
- b) Test-And-Set
- c) Disabling scheduling
- d) Using semaphores

#### 2.19.01 Mutual Exclusion, Disabling and enabling interrupts

The easiest and fastest way to gain exclusive access to a shared resource is by disabling and enabling interrupts as shown in the pseudo-code of listing 2.3.

```
Disable interrupts;  
Access the resource (read/write from/to variables);  
Reenable interrupts;
```

**Listing 2.3, Disabling/enabling interrupts.**

$\mu$  C/OS-II uses this technique (as do most, if not all kernels) to access internal variables and data structures. In fact,  $\mu$  C/OS-II provides two macros to allow you to disable and then enable interrupts from your C code:

`OS_ENTER_CRITICAL()` and `OS_EXIT_CRITICAL()`, respectively (see section 8.03.02, *OS\_CPU.H*, *OS\_ENTER\_CRITICAL()* and *OS\_EXIT\_CRITICAL()*). You need to use these macros in pair as shown in listing 2.4.

```
void Function (void)
{
    OS_ENTER_CRITICAL();
    .
    .    /* You can access shared data in here */
    .
    OS_EXIT_CRITICAL();
}
```

### **Listing 2.4, Using $\mu$ C/OS-II's macros to disable/enable interrupts.**

You must be careful, however, to not disable interrupts for too long because this affects the response of your system to interrupts. This is known as *interrupt latency*. You should consider this method when you are changing or copying a few variables. Also, this is the only way that a task can share variables or data structures with an ISR. In all cases, you should keep interrupts disabled for as little time as possible.

If you use a kernel, you are basically allowed to disable interrupts for as much time as the kernel does without affecting interrupt latency. Obviously, you need to know how long the kernel will disable interrupts. Any good kernel vendor will provide you with this information. After all, if they sell a real-time kernel, time is important!



### 2.19.02 Mutual Exclusion, Test-And-Set

If you are not using a kernel, two functions could 'agree' that to access a resource, they must check a global variable, and if the variable is **0** the function has access to the resource. To prevent the other function from accessing the resource, however, the first function that gets the resource simply sets the variable to **1**. This is commonly called a *Test-And-Set* (or TAS) operation. The TAS operation must either be performed indivisibly (by the processor) or you must disable interrupts when doing the TAS on the variable as shown in listing 2.5.

```
Disable interrupts;
if ('Access Variable' is 0) {
    Set variable to 1;
    Reenable interrupts;
    Access the resource;
    Disable interrupts;
    Set the 'Access Variable' back to 0;
    Reenable interrupts;
} else {
    Reenable interrupts;
    /* You don't have access to the resource, try back later; */
}
```

**Listing 2.5, Using Test-And-Set to access a resource.**

Some processors actually implement a TAS operation in hardware (e.g. the 68000 family of processors have the **TAS** instruction).

### 2.19.03 Mutual Exclusion, Disabling and enabling the scheduler

If your task is not sharing variables or data structures with an ISR then you can disable/enable scheduling (see section 3.06, *Locking and Unlocking the Scheduler*) as shown in listing 2.6 (using  $\mu$  C/OS-II as an example). In this case, two or more tasks can share data without the possibility of contention. You should note that while the scheduler is locked, interrupts are enabled and, if an interrupt occurs while in the critical section, the ISR will immediately be executed. At the end of the ISR, the kernel will always return to the interrupted task even if a higher priority task has been made ready-to-run by the ISR. The scheduler will be invoked when **OSSchedUnlock()** is called to see if a higher priority task has been made ready to run by the task or an ISR. A context switch will result if there is a higher priority task that is ready to run. Although this method works well, you should avoid disabling the scheduler because it defeats the purpose of having a kernel in the first place. The next method should be chosen instead.

```
void Function (void)
{
    OSSchedLock();
    .
    .    /* You can access shared data in here (interrupts are recognized) */
    .
    OSSchedUnlock();
}
```

**Listing 2.6, Accessing shared data by disabling/enabling scheduling.**

### 2.19.04 Mutual Exclusion, Semaphores

The semaphore was invented by Edsger Dijkstra in the mid 1960s. A semaphore is a protocol mechanism offered by most multitasking kernels. Semaphores are used to:

- a) control access to a shared resource (mutual exclusion);
- b) signal the occurrence of an event;
- c) allow two tasks to synchronize their activities.

A semaphore is a key that your code acquires in order to continue execution. If the semaphore is already in use, the requesting task is suspended until the semaphore is released by its current owner. In other words, the requesting task says: "Give me the key. If someone else is using it, I am willing to wait for it!"

There are two types of semaphores: *binary* semaphores and *counting* semaphores. As its name implies, a binary semaphore can only take two values: **0** or **1**. A counting semaphore allows values between **0** and **255**, **65535** or **4294967295**, depending on whether the semaphore mechanism is implemented using 8, 16 or 32 bits, respectively. The actual size depends on the kernel used. Along with the semaphore's value, the kernel also needs to keep track of tasks waiting for the semaphore's availability.

There are generally only three operations that can be performed on a semaphore: **INITIALIZE** (also called *CREATE*), **WAIT** (also called *PEND*), and **SIGNAL** (also called *POST*).

The initial value of the semaphore must be provided when the semaphore is initialized. The waiting list of tasks is always initially empty.

A task desiring the semaphore will perform a **WAIT** operation. If the semaphore is available (the semaphore value is greater than **0**), the semaphore value is decremented and the task continues execution. If the semaphore's value is **0**, the task performing a **WAIT** on the semaphore is placed in a waiting list. Most kernels allow you to specify a timeout; if the semaphore is not available within a certain amount of time, the requesting task is made ready to run and an error code (indicating that a timeout has occurred) is returned to the caller.

A task releases a semaphore by performing a **SIGNAL** operation. If no task is waiting for the semaphore, the semaphore value is simply incremented. If any task is waiting for the semaphore, however, one of the tasks is made ready to run and the semaphore value is not incremented; the key is given to one of the tasks waiting for it. Depending on the kernel, the task which will receive the semaphore is either:

- a) the highest priority task waiting for the semaphore, or
- b) the first task that requested the semaphore (First In First Out, or FIFO).

Some kernels allow you to choose either method through an option when the semaphore is initialized.  $\mu$  C/OS-II only supports the first method. If the readied task has a higher priority than the current task (the task releasing the semaphore), a context switch will occur (with a preemptive kernel) and the higher priority task will resume execution; the current task will be suspended until it again becomes the highest priority task ready-to-run.

Listing 2.7 shows how you can share data using a semaphore (using  $\mu$  C/OS-II). Any task needing access to the same shared data will call **OSSemPend( )** and when the task is done with the data, the task calls **OSSemPost( )**. Both of these functions will be described later. You should note that a semaphore is an object that needs to be initialized before it's used and for mutual exclusion, a semaphore is initialized to a value of **1**. Using a semaphore to access shared data doesn't affect interrupt latency and, if an ISR or the current task makes a higher priority task ready-to-run while accessing the data then, this higher priority task will execute immediately.

```
OS_EVENT *SharedDataSem;

void Function (void)
{
    INT8U err;

    OSSemPend(SharedDataSem, 0, &err);
    .
    .    /* You can access shared data in here (interrupts are recognized) */
    .
    OSSemPost(SharedDataSem);
}
```

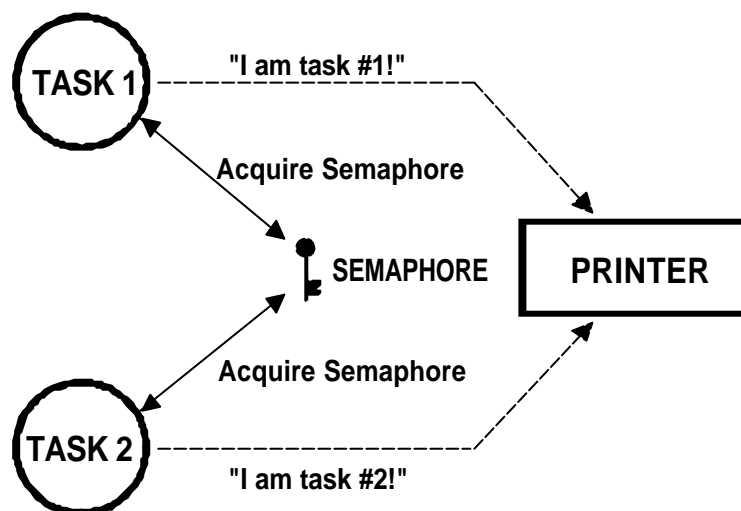
### Listing 2.7, Accessing shared data by obtaining a semaphore.

Semaphores are especially useful when tasks are sharing I/O devices. Imagine what would happen if two tasks were allowed to send characters to a printer at the same time. The printer would contain interleaved data from each task. For instance, if task #1 tried to print “ I am task #1!” and task #2 tried to print “I am task #2!” then the printout could look like this:

I I a am m t tasask k#1 #!2!

In this case, we can use a semaphore and initialize it to 1 (i.e. a binary semaphore). The rule is simple: to access the printer each task must first obtain the resource's semaphore. Figure 2-9 shows the tasks competing for a semaphore to gain exclusive access to the printer. Note that the semaphore is represented symbolically by a key indicating that each task must obtain this key to use the printer.

The above example implies that each task must know about the existence of the semaphore in order to access the resource. There are situations when it is better to encapsulate the semaphore. Each task would thus not know that it is actually acquiring a semaphore when accessing the resource. For example, an RS-232C port is used by multiple tasks to send commands and receive responses from a device connected at the other end of the RS-232C port. A flow diagram is shown in Figure 2-10.



**Figure 2-9, Using a semaphore to get permission to access a printer.**

The function `CommSendCmd()` is called with three arguments: the ASCII string containing the command, a pointer to the response string from the device, and finally, a timeout in case the device doesn't respond within a certain amount of time. The pseudo-code for this function is:

```
INT8U CommSendCmd(char *cmd, char *response, INT16U timeout)
{
    Acquire port's semaphore;
    Send command to device;
    Wait for response (with timeout);
    if (timed out) {
        Release semaphore;
        return (error code);
    } else {
```

```

    Release semaphore;
    return (no error);
}
}

```

### Listing 2.8, Encapsulating a semaphore.

Each task which needs to send a command to the device has to call this function. The semaphore is assumed to be initialized to 1 (i.e., available) by the communication driver initialization routine. The first task that calls **CommSendCmd()** will acquire the semaphore and thus proceed to send the command and wait for a response. If another task attempts to send a command while the port is busy, this second task will be suspended until the semaphore is released. The second task appears to have simply made a call to a normal function that will not return until the function has performed its duty. When the semaphore is released by the first task, the second task will acquire the semaphore and will thus be allowed to use the RS-232C port.

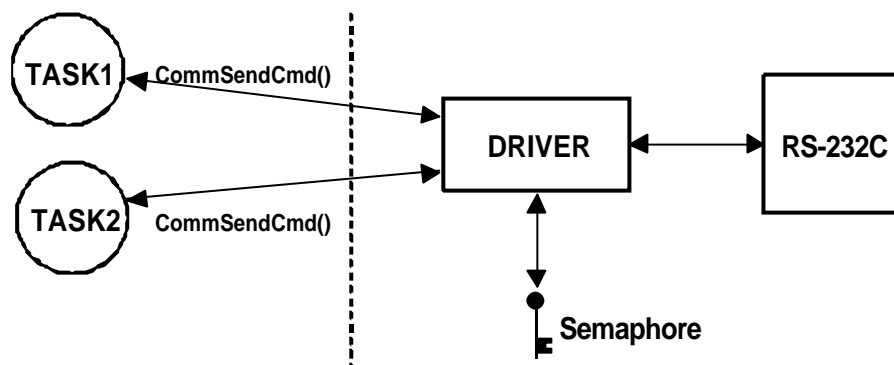


Figure 2-10, Hiding a semaphore from tasks.

A counting semaphore is used when a resource can be used by more than one task at the same time. For example, a counting semaphore is used in the management of a buffer pool as shown in Figure 2-11. Let's assume that the buffer pool initially contains 10 buffers. A task would obtain a buffer from the buffer manager by calling **BufReq()**. When the buffer is no longer needed, the task would return the buffer to the buffer manager by calling **BufRel()**. The pseudocode for these functions is shown in listing 2.9.

```

BUF *BufReq(void)
{
    BUF *ptr;

    Acquire a semaphore;
    Disable interrupts;
    ptr = BufFreeList;
    BufFreeList = ptr->BufNext;
    Enable interrupts;
    return (ptr);
}

void BufRel(BUF *ptr)
{
    Disable interrupts;
    ptr->BufNext = BufFreeList;
}

```

```

BufFreeList = ptr;
Enable interrupts;
Release semaphore;
}

```

### Listing 2.9, Buffer management using a semaphore.

The buffer manager will satisfy the first 10 buffer requests (since there are 10 keys). When all semaphores are used, a task requesting a buffer would be suspended until a semaphore becomes available. Interrupts are disabled to gain exclusive access to the linked list (this operation is very quick). When a task is finished with the buffer it acquired, it calls **BufRel()** to return the buffer to the buffer manager; the buffer is inserted into the linked list before the semaphore is released. By encapsulating the interface to the buffer manager in **BufReq()** and **BufRel()**, the caller doesn't need to be concerned with the actual implementation details.

Semaphores are often overused. The use of a semaphore to access a simple shared variable is overkill in most situations. The overhead involved in acquiring and releasing the semaphore can consume valuable time. You can do the job just as efficiently by disabling and enabling interrupts (see section 2.19.01, *Mutual Exclusion, Disabling and Enabling Interrupts*). Let's suppose that two tasks are sharing a 32-bit integer variable. The first task increments the variable while the other task clears it. If you consider how long a processor takes to perform either operation, you will realize that you do not need a semaphore to gain exclusive access to the variable. Each task simply needs to disable interrupts before performing its operation on the variable and enable interrupts when the operation is complete. A semaphore should be used, however, if the variable is a floating-point variable and the microprocessor doesn't support floating-point in hardware. In this case, the processing time involved in processing the floating-point variable could affect interrupt latency if you had disabled interrupts.

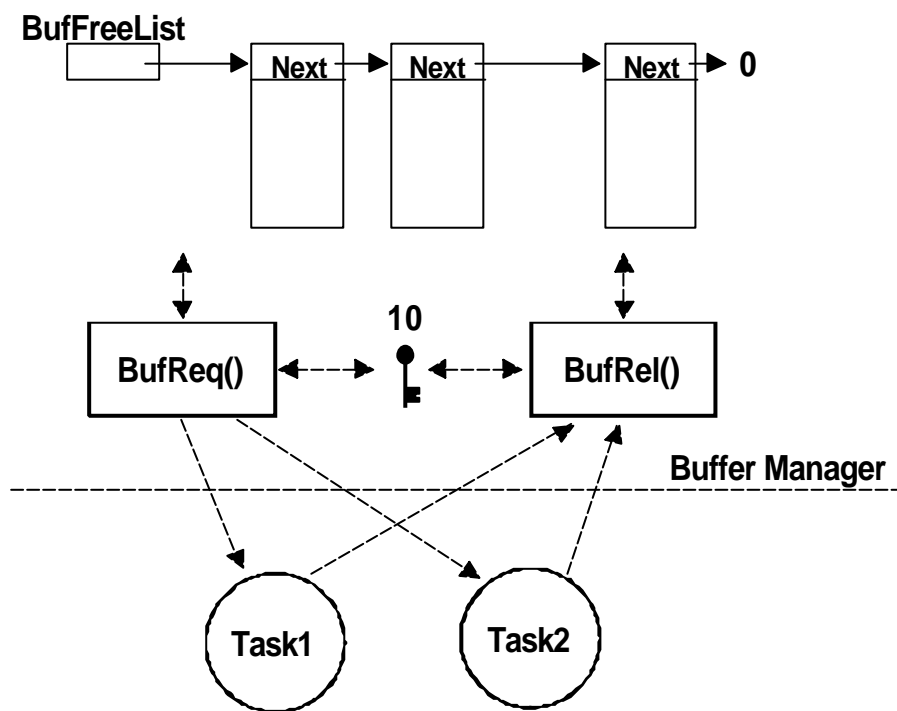


Figure 2-11, Using a counting semaphore.

## 2.20 Deadlock (or Deadly Embrace)

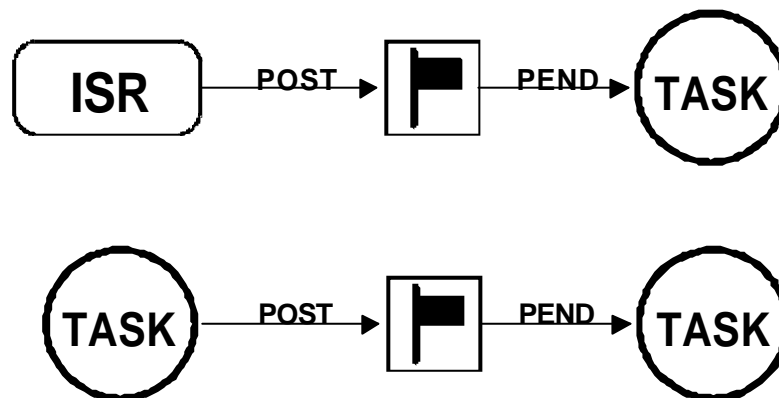
A deadlock, also called *adeadlyembrace*, is a situation in which two tasks are each unknowingly waiting for resources held by each other. If task T1 has exclusive access to resource R1 and task T2 has exclusive access to resource R2, then if T1 needs exclusive access to R2 and T2 needs exclusive access to R1, neither task can continue. They are deadlocked. The simplest way to avoid a deadlock is for tasks to:

- a) acquire all resources before proceeding,
- b) acquire the resources in the same order, and
- c) release the resources in the reverse order.

Most kernels allow you to specify a timeout when acquiring a semaphore. This feature allows a deadlock to be broken. If the semaphore is not available withing a certain amount of time, the task requesting the resource will resume execution. Some form of error code must be returned to the task to notify it that a timeout has occurred. A return error code prevents the task from thinking it has obtained to the resource. Deadlocks generally occur in large multitasking systems and are not generally encountered in embedded systems.

## 2.21 Synchronization

A task can be synchronized with an ISR, or another task when no data is being exchanged, by using a semaphore as shown in Figure 2-12. Note that, in this case, the semaphore is drawn as a flag, to indicate that it is used to signal the occurrence of an event (rather than to ensure mutual exclusion, in which case it would be drawn as a key). When used as a synchronization mechanism, the semaphore is initialized to 0. Using a semaphore for this type of synchronization is using what is called a *unilateral rendezvous*. A task initiates an I/O operation and then waits for the semaphore. When the I/O operation is complete, an ISR (or another task) signals the semaphore and the task is resumed.



**Figure 2-12, Synchronizing tasks and ISRs.**

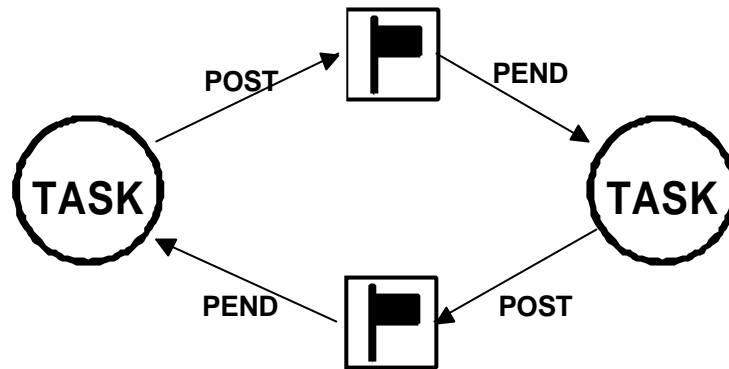
If the kernel supports counting semaphores, the semaphore would accumulate events that have not yet been processed.

Note that more than one task can be waiting for the event to occur. In this case, the kernel could signal the occurrence of the event either to:

- a) the highest priority task waiting for the event to occur, or
- b) the first task waiting for the event.

Depending on the application, more than one ISR or task could signal the occurrence of the event.

Two tasks can synchronize their activities by using two semaphores, as shown in Figure 2-13. This is called *abilateral rendezvous*. A bilateral rendezvous is similar to a unilateral rendezvous except both tasks must synchronize with one another before proceeding.



**Figure 2-13, Tasks synchronizing their activities.**

For example, two tasks are executing as shown in listing 2.10. When the first task reaches a certain point, it signals the second task L2.10(1) and then waits for a signal from the second task L2.10(2). Similarly, when the second task reaches a certain point, it signals the first task L2.10(3) and then waits for a signal from the first task L2.10(4). At this point, both tasks are synchronized with each other. A bilateral rendezvous cannot be performed between a task and an ISR because an ISR cannot wait on a semaphore.

```

Task1()
{
    for (;;) {
        Perform operation;
        Signal task #2;           (1)
        Wait for signal from task #2; (2)
        Continue operation;
    }
}

Task2()
{
    for (;;) {
        Perform operation;
        Signal task #1;           (3)
        Wait for signal from task #1; (4)
        Continue operation;
    }
}
  
```

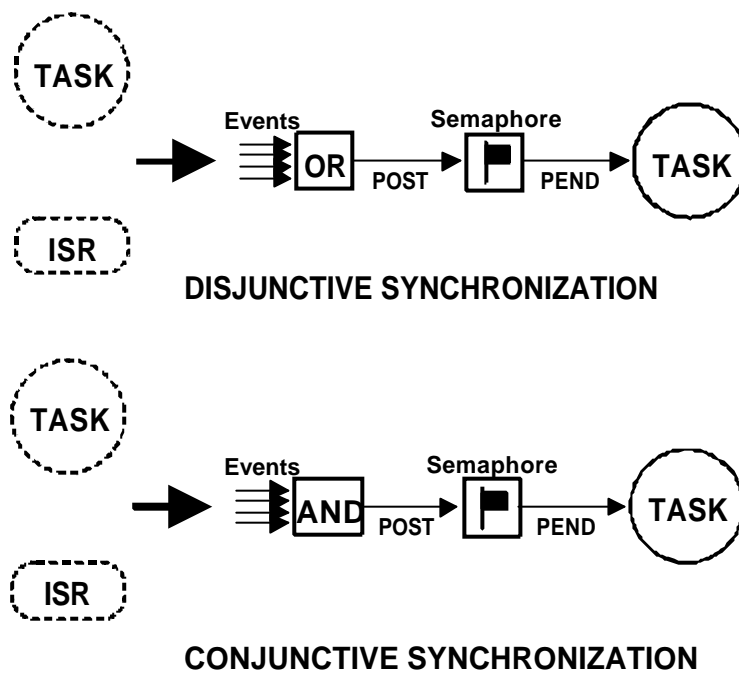
**Listing 2.10, Bilateral rendezvous.**

## 2.22 Event Flags

Event flags are used when a task needs to synchronize with the occurrence of multiple events. The task can be synchronized when any of the events have occurred. This is called *disjunctive synchronization* (logical OR). A task can also be synchronized when all events have occurred. This is called *conjunctive synchronization* (logical AND). Disjunctive and conjunctive synchronization are shown in Figure 2-14.

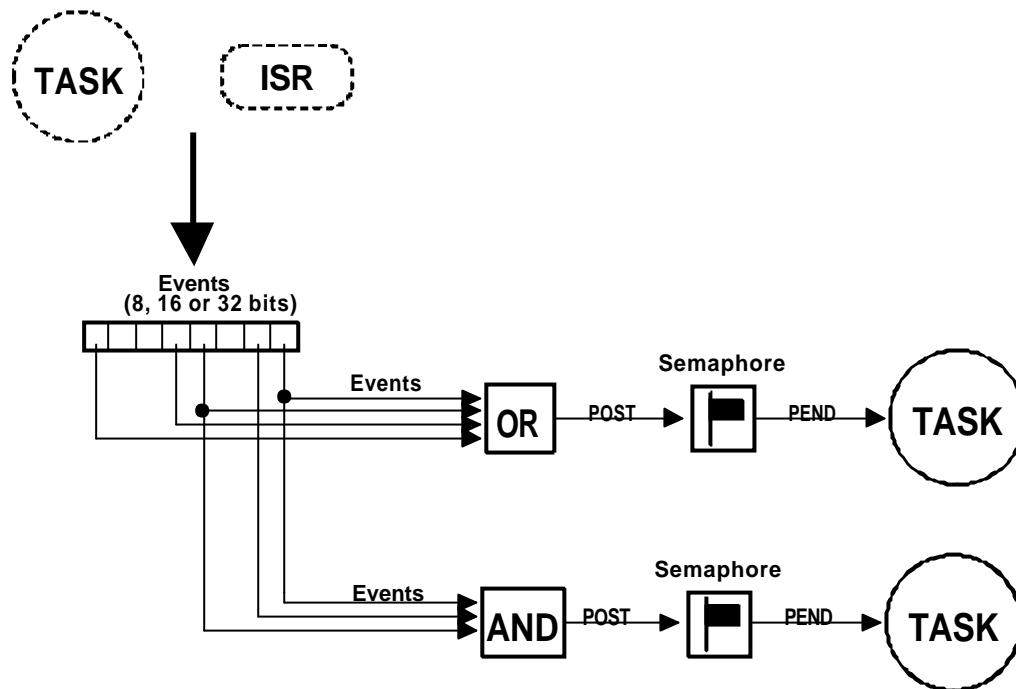
Common events can be used to signal multiple tasks, as shown in Figure 2-15. Events are typically grouped. Depending on the kernel, a group consists of 8, 16 or 32 events (mostly 32-bits, though). Tasks and ISRs can set or clear any event in a group. A task is resumed when all the events it requires are satisfied. The evaluation of which task will be resumed is performed when a new set of events occurs (i.e. during a SET operation).

Kernels supporting event flags offer services to SET event flags, CLEAR event flags, and WAIT for event flags (conjunctively or disjunctively).  $\mu$  C/OS-II does not currently support event flags.



**Figure 2-14, Disjunctive and conjunctive synchronization.**





**Figure 2-15, Event flags.**

## 2.23 Intertask Communication

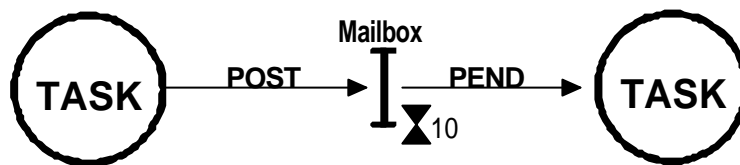
It is sometimes necessary for a task or an ISR to communicate information to another task. This information transfer is called *intertask communication*. Information may be communicated between tasks in two ways: through global data or by sending messages.

When using global variables, each task or ISR must ensure that it has exclusive access to the variables. If an ISR is involved, the only way to ensure exclusive access to the common variables is to disable interrupts. If two tasks are sharing data each can gain exclusive access to the variables by using either disabling/enabling interrupts or through a semaphore (as we have seen). Note that a task can only communicate information to an ISR by using global variables. A task is not aware when a global variable is changed by an ISR unless the ISR signals the task by using a semaphore or by having the task regularly poll the contents of the variable. To correct this situation, you should consider using either a *message mailbox* or a *message queue*.

## 2.24 Message Mailboxes

Messages can be sent to a task through kernel services. A Message Mailbox, also called a message exchange, is typically a pointer size variable. Through a service provided by the kernel, a task or an ISR can deposit a message (the pointer) into this mailbox. Similarly, one or more tasks can receive messages through a service provided by the kernel. Both the sending task and receiving task will agree as to what the pointer is actually pointing to.

A waiting list is associated with each mailbox in case more than one task desires to receive messages through the mailbox. A task desiring to receive a message from an empty mailbox will be suspended and placed on the waiting list until a message is received. Typically, the kernel will allow the task waiting for a message to specify a timeout. If a message is not received before the timeout expires, the requesting task is made ready-to-run and an error code (indicating that a timeout has occurred) is returned to it. When a message is deposited into the mailbox, either the highest priority task waiting for the message is given the message (called *priority-based*) or the first task to request a message is given the message (called *First-In-First-Out*, or FIFO). Figure 2-16 shows a task depositing a message into a mailbox. Note that the mailbox is represented graphically by an I-beam and the timeout is represented by an hourglass. The number next to the hourglass represents the number of clock ticks (described later) that the task will wait for a message to arrive.



**Figure 2-16, Message mailbox.**

Kernel services are typically provided to:

- Initialize the contents of a mailbox. The mailbox may or may not initially contain a message.
- Deposit a message into the mailbox (POST).
- Wait for a message to be deposited into the mailbox (PEND).
- Get a message from a mailbox, if one is present, but not suspend the caller if the mailbox is empty (ACCEPT). If the mailbox contains a message, the message is extracted from the mailbox. A return code is used to notify the caller about the outcome of the call.

Message mailboxes can also be used to simulate binary semaphores. A message in the mailbox indicates that the resource is available while an empty mailbox indicates that the resource is already in use by another task.

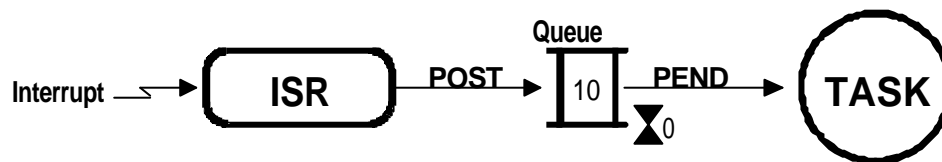
## 2.25 Message Queues

A message queue is used to send one or more messages to a task. A message queue is basically an array of mailboxes. Through a service provided by the kernel, a task or an ISR can deposit a message (the pointer) into a message queue. Similarly, one or more tasks can receive messages through a service provided by the kernel. Both the sending task and receiving task will agree as to what the pointer is actually pointing to. Generally, the first message inserted in the queue will be the first message extracted from the queue (FIFO). In addition to extract messages in a FIFO fashion,  $\mu$ COS-II allows a task to get messages *Last-In-First-Out* (LIFO).

As with the mailbox, a waiting list is associated with each message queue in case more than one task is to receive messages through the queue. A task desiring to receive a message from an empty queue will be suspended and placed on the waiting list until a message is received. Typically, the kernel will allow the task waiting for a message to specify a timeout. If a message is not received before the timeout expires, the requesting task is made ready-to-run and an error code (indicating a timeout occurred) is returned to it. When a message is deposited into the queue, either the highest priority task or the first task to wait for the message will be given the message. Figure 2-17 shows an ISR (Interrupt Service Routine) depositing a message into a queue. Note that the queue is represented graphically by a double I-beam. The **10** indicates the number of messages that can be accumulated in the queue. A **0** next to the hourglass indicates that the task will wait forever for a message to arrive.

Kernel services are typically provided to:

- Initialize the queue. The queue is always assumed to be empty after initialization.
- Deposit a message into the queue (POST).
- Wait for a message to be deposited into the queue (PEND).
- Get a message from a queue, if one is present, but not suspend the caller if the queue is empty (ACCEPT). If the queue contained a message, the message is extracted from the queue. A return code is used to notify the caller about the outcome of the call.



**Figure 2-17, Message queue.**

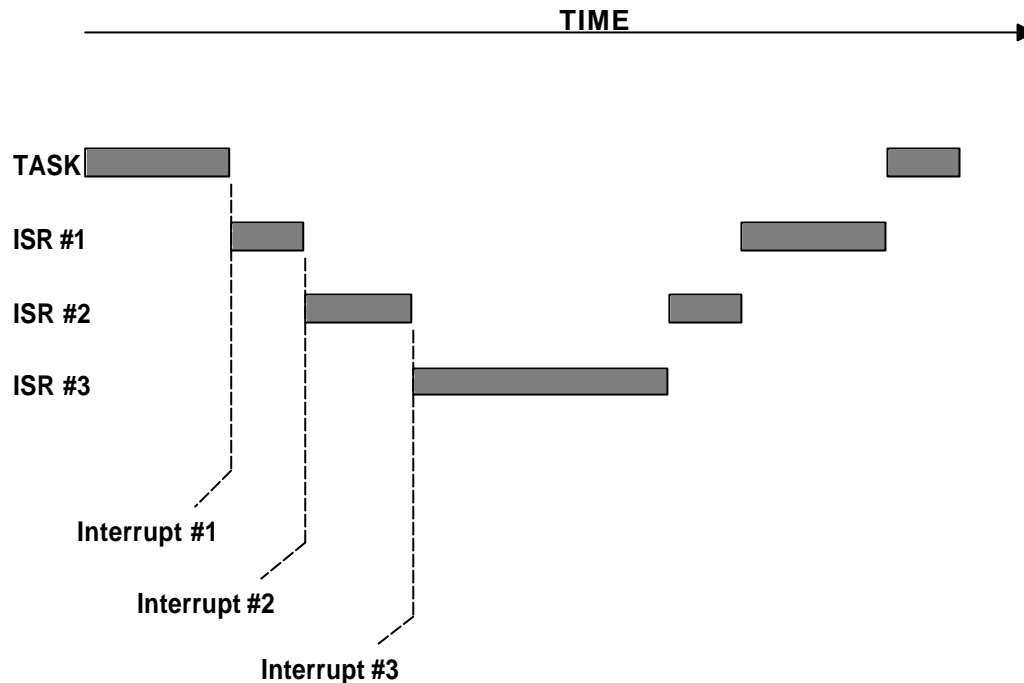
## 2.26 Interrupts

An interrupt is a hardware mechanism used to inform the CPU that an asynchronous event has occurred. When an interrupt is recognized, the CPU saves part (or all) of its context (i.e. registers) and jumps to a special subroutine called an *Interrupt Service Routine*, or *ISR*. The ISR processes the event and upon completion of the ISR, the program returns to:

- The background for a foreground/background system.
- The interrupted task for a non-preemptive kernel.
- The highest priority task ready-to-run for a preemptive kernel.

Interrupts allow a microprocessor to process events when they occur. This prevents the microprocessor from continuously *polling* an event to see if this event has occurred. Microprocessors allow interrupts to be ignored and recognized through the use of two special instructions: *disable interrupts* and *enable interrupts*, respectively. In a real-time environment, interrupts should be disabled as little as possible. Disabling interrupts affects interrupt latency (see section 2.27, *Interrupt Latency*) and also, disabling interrupts may cause interrupts to be missed. Processors

generally allow interrupts to be *nested*. This means that while servicing an interrupt, the processor will recognize and service other (more important) interrupts as shown in Figure 2-18.



**Figure 2-18, Interrupt nesting.**

## 2.27 Interrupt Latency

Probably the most important specification of a real-time kernel is the amount of time interrupts are disabled. All real-time systems disable interrupts to manipulate critical sections of code and re-enable interrupts when the critical section has executed. The longer interrupts are disabled, the higher the *interrupt latency*. Interrupt latency is given by:

$$\text{Maximum amount of time interrupts are disabled} + \text{Time to start executing the first instruction in the ISR}$$

**Equation 2.2, Interrupt latency.**

## 2.28 Interrupt Response

Interrupt response is defined as the time between the reception of the interrupt and the start of the user code which will handle the interrupt. The interrupt response time accounts for all the overhead involved in handling an interrupt. Typically, the processor's context (CPU registers) is saved on the stack before the user code is executed.

For a foreground/background system, the user ISR code is executed immediately after saving the processor's context. The response time is given by:

$$\text{Interrupt latency} + \text{Time to save the CPU's context}$$

### Equation 2.3, Interrupt response, foreground/background system.

For a non-preemptive kernel, the user ISR code is executed immediately after the processor's context is saved. The response time to an interrupt for a non-preemptive kernel is given by:

$$\text{Interrupt latency} + \text{Time to save the CPU's context}$$

### Equation 2.4, Interrupt response, Non-preemptive kernel.

For a preemptive kernel, a special function provided by the kernel needs to be called. This function notifies the kernel that an ISR is in progress and allows the kernel to keep track of interrupt nesting. For  $\mu$  C/OS-II, this function is called **OSIntEnter()**. The response time to an interrupt for a preemptive kernel is given by:

$$\text{Interrupt latency} + \text{Time to save the CPU's context} + \text{Execution time of the kernel ISR entry function}$$

### Equation 2.5, Interrupt response, Preemptive kernel.

A system's worst case interrupt response time is its only response. Your system may respond to interrupts in 50  $\mu$  S 99 percent of the time, but if it responds to interrupts in 250  $\mu$  S the other 1 percent, you must assume a 250  $\mu$  S interrupt response time.

## 2.29 Interrupt Recovery

Interrupt recovery is defined as the time required for the processor to return to the interrupted code.

Interrupt recovery in a foreground/background system simply involves restoring the processor's context and returning to the interrupted task. Interrupt recovery is given by:

$$\text{Time to restore the CPU's context} + \text{Time to execute the return from interrupt instruction}$$

### Equation 2.6, Interrupt recovery, Foreground/background system.

As with a foreground/background system, interrupt recovery with a non-preemptive kernel simply involves restoring the processor's context and returning to the interrupted task. Interrupt recovery is thus:

$$\text{Time to restore the CPU's context} + \text{Time to execute the return from interrupt instruction}$$

### Equation 2.7, Interrupt recovery, Non-preemptive kernel.

For a preemptive kernel, interrupt recovery is more complex. Typically, a function provided by the kernel is called at the end of the ISR. For  $\mu$  C/OS-II, this function is called **OSIntExit()** and allows the kernel to determine if all interrupts have nested. If all interrupts have nested (i.e. a return from interrupt will return to task level code), the kernel

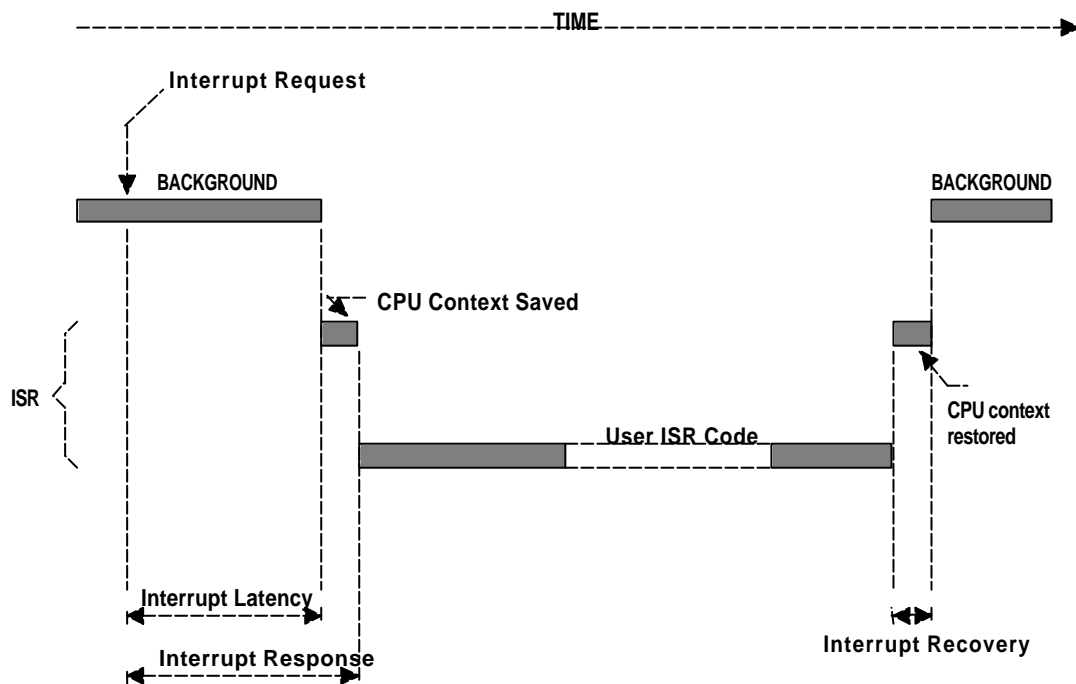
will determine if a higher priority task has been made ready-to-run as a result of the ISR. If a higher priority task is ready-to-run as a result of the ISR, this task is resumed. Note that, in this case, the interrupted task will be resumed only when it again becomes the highest priority task ready-to-run. For a preemptive kernel, interrupt recovery is given by:

$$\begin{aligned} &\text{Time to determine if a higher priority task is ready} + \\ &\text{Time to restore the CPU's context of the highest priority task} + \\ &\text{Time to execute the return from interrupt instruction} \end{aligned}$$

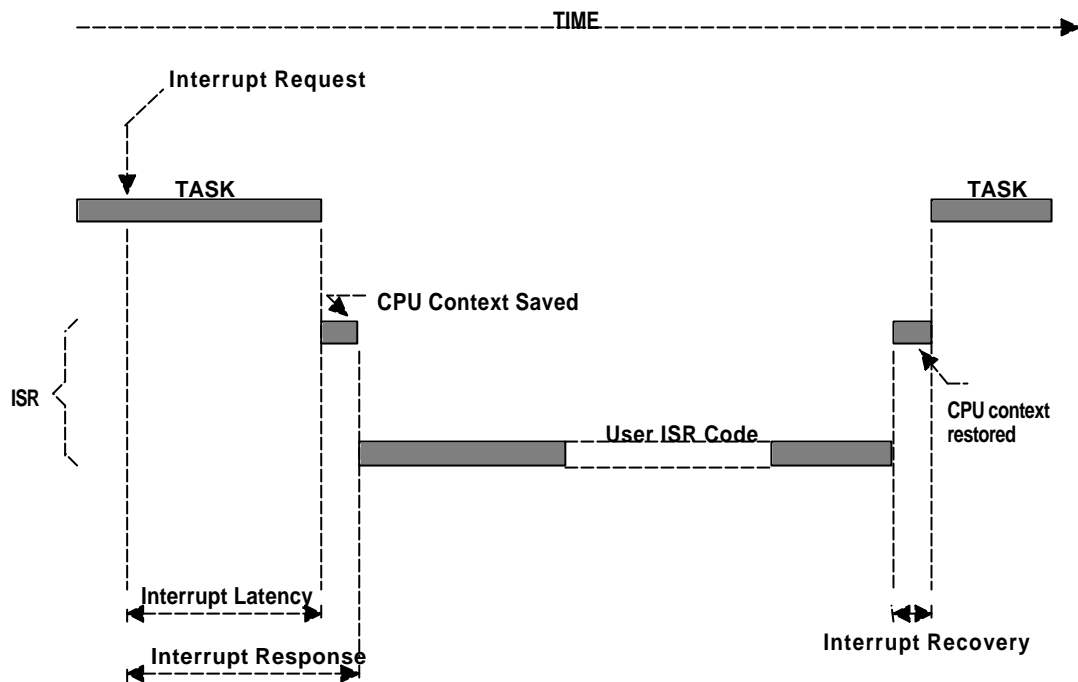
**Equation 2.8, Interrupt recovery, Non-preemptive kernel.**

### 2.30 Interrupt Latency, Response, and Recovery

Figures 2-19, 2-20 and 2-21 show the interrupt latency, response, and recovery for a foreground/background system, a non-preemptive kernel, and a preemptive kernel, respectively.

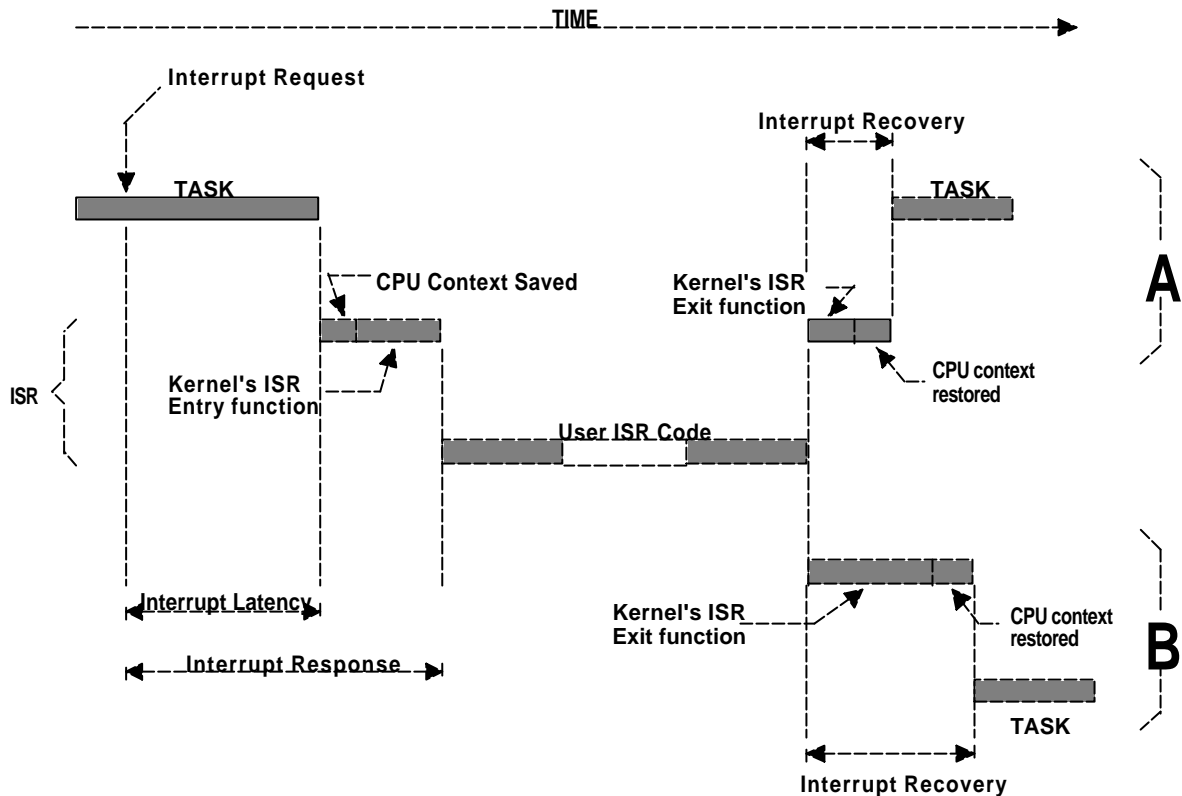


**Figure 2-19, Interrupt latency, response, and recovery  
(Foreground/Background)**



**Figure 2-20, Interrupt latency, response, and recovery  
(Non-preemptive kernel)**

You should note that for a preemptive kernel, the exit function either decides to return to the interrupted task F2-21A or to a higher priority task that the ISR has made ready-to-run F2-21B. In the later case, the execution time is slightly longer because the kernel has to perform a context switch. I made the difference in execution time somewhat to scale assuming  $\mu$  C/OS-II on an Intel 80186 processor (see Table 9.3, *Execution times of  $\mu$  C/OS-II services on 33 MHz 80186*). This allows you to see the cost (in execution time) of switching context.



**Figure 2-21, Interrupt latency, response, and recovery  
(Preemptive kernel)**

### 2.31 ISR Processing Time

While ISRs should be as short as possible, there are no absolute limits on the amount of time for an ISR. One cannot say that an ISR must always be less than 100  $\mu$  S, 500  $\mu$  S, 1 mS, etc. If the ISR's code is the most important code that needs to run at any given time, then it could be as long as it needs to be. In most cases, however, the ISR should recognize the interrupt, obtain data/status from the interrupting device, and signal a task which will perform the actual processing. You should also consider whether the overhead involved in signaling a task is more than the processing of the interrupt. Signaling a task from an ISR (i.e. through a semaphore, a mailbox, or a queue) requires some processing time. If processing of your interrupt requires less than the time required to signal a task, you should consider processing the interrupt in the ISR itself and possibly enable interrupts to allow higher priority interrupts to be recognized and serviced.

### 2.32 Non-Maskable Interrupts (NMIs)

Sometimes, an interrupt must be serviced as quickly as possible and cannot afford to have the latency imposed by a kernel. In these situations, you may be able to use the *Non-Maskable Interrupt* (NMI) provided on most microprocessors. Since the NMI cannot be disabled, interrupt latency, response, and recovery are minimal. The NMI is generally reserved for drastic measures such as saving important information during a power down. If, however, your application doesn't have this requirement, you could use the NMI to service your most time-critical ISR. Equations 2.9, 2.10 and 2.11 shows how to determine the interrupt latency, response and recovery of an NMI, respectively.



Time to execute longest instruction +  
Time to start executing the NMI ISR

### Equation 2.9, Interrupt latency for an NMI.

Interrupt latency +  
Time to save the CPU's context

### Equation 2.10, Interrupt response for an NMI.

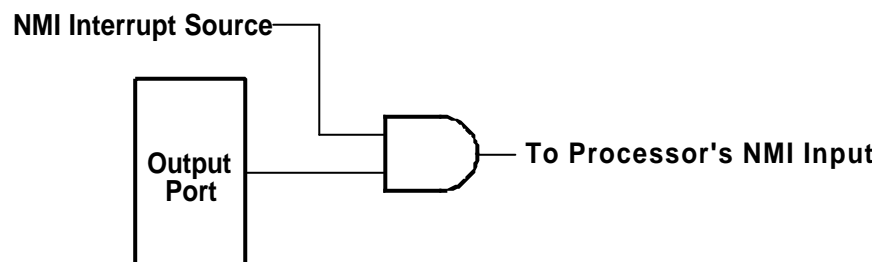
Time to restore the CPU's context +  
Time to execute the return from interrupt instruction

### Equation 2.11, Interrupt recovery of an NMI.

I have used the NMI in an application to respond to an interrupt which could occur every 150  $\mu$  S. The processing time of the ISR took from 80 to 125  $\mu$  S and the kernel I used disabled interrupts for about 45  $\mu$  S. As you can see, if I had used maskable interrupts, the ISR could have been late by 20  $\mu$  S.

When you are servicing an NMI, you cannot use kernel services to signal a task because NMIs cannot be disabled to access critical sections of code. You can, however, still pass parameters to and from the NMI. Parameters passed must be global variables and the size of these variables must be read or written indivisibly, that is, not as separate byte read or write instructions.

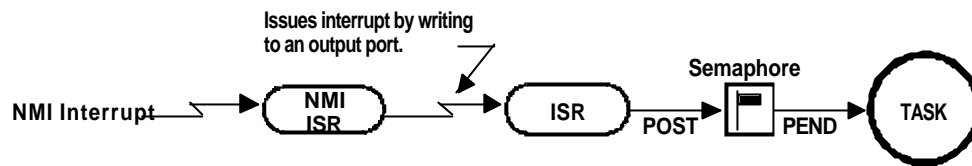
NMIs can be disabled by adding external circuitry, as shown in Figure 2-22. Assuming that both the interrupt and the NMI are positive going signals, a simple AND gate is inserted between the interrupt source and the processor's NMI input. Interrupts are disabled by writing a 0 to an output port. You wouldn't want to disable interrupts to use kernel services, but you could use this feature to pass parameters (i.e. larger variables) to and from the ISR and a task.



**Figure 2-22, Disabling non-maskable interrupts.**

Now, let's suppose that the NMI service routine needs to signal a task every 40 times it executes. If the NMI occurs every 150  $\mu$  S, a signal would be required every 6 mS (40 x 150  $\mu$  S). From a NMI ISR, you cannot use the kernel to signal the task, but you could use the scheme shown in Figure 2-23. In this case, the NMI service routine would generate a hardware interrupt through an output port (i.e. bringing an output high). Since the NMI service routine typically has the highest priority and, interrupt nesting is typically not allowed while servicing the NMI ISR, the interrupt would not be recognized until the end of the NMI service routine. At the completion of the NMI service routine, the processor would be interrupted to service this hardware interrupt. This ISR would clear the interrupt

source (i.e. bring the port output low) and post to a semaphore that would wake up the task. As long as the task services the semaphore well within 6 mS, your deadline would be met.



**Figure 2-23, Signaling a task from a non-maskable interrupt.**

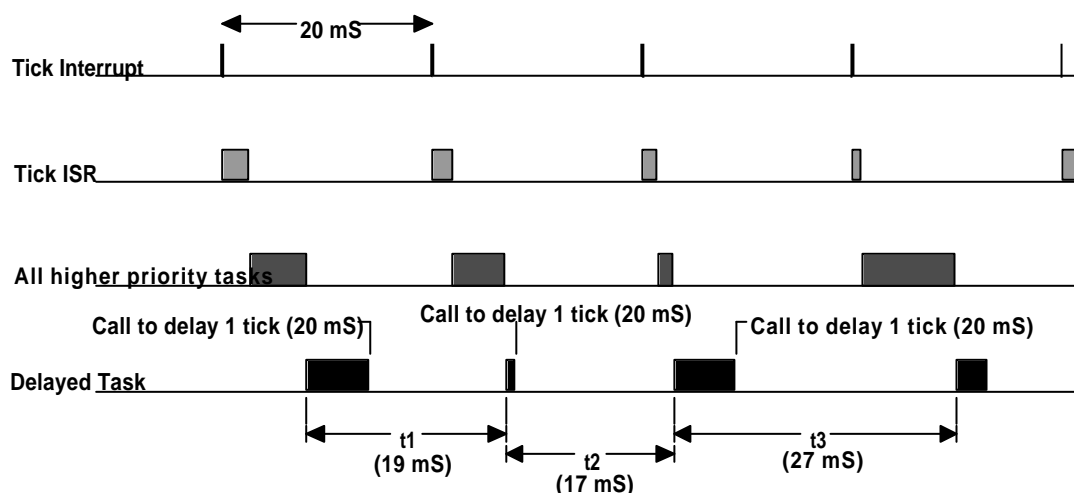
## 2.33 Clock Tick

A *clock tick* is a special interrupt that occurs periodically. This interrupt can be viewed as the system's heartbeat. The time between interrupts is application specific and is generally between 10 and 200 mS. The clock tick interrupt allows a kernel to delay tasks for an integral number of clock ticks and to provide timeouts when tasks are waiting for events to occur. The faster the tick rate, the higher the overhead imposed on the system.

All kernels allow tasks to be delayed for a certain number of clock ticks. The resolution of delayed tasks is 1 clock tick, however, this does not mean that its accuracy is 1 clock tick.

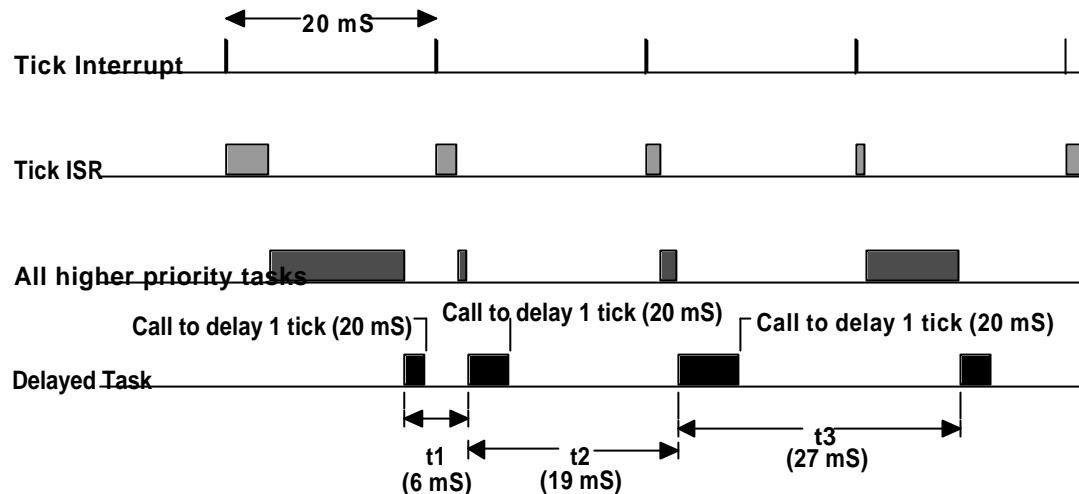
Figures 2-24 through 2-26 are timing diagrams showing a task delaying itself for 1 clock tick. The shaded areas indicate the execution time for each operation being performed. Note that the time for each operation varies to reflect typical processing, which would include loops and conditional statements (i.e., if/else, switch and ?). The processing time of the 'Tick ISR' has been exaggerated to show that it too is subject to varying execution times.

Case 1 (Figure 2-24) shows a situation where higher priority tasks and ISRs execute prior to the task, which needs to delay for 1 tick. As you can see, the task attempts to delay for 20 mS but because of its priority, actually executes at varying intervals. This will thus cause the execution of the task to *jitter*.



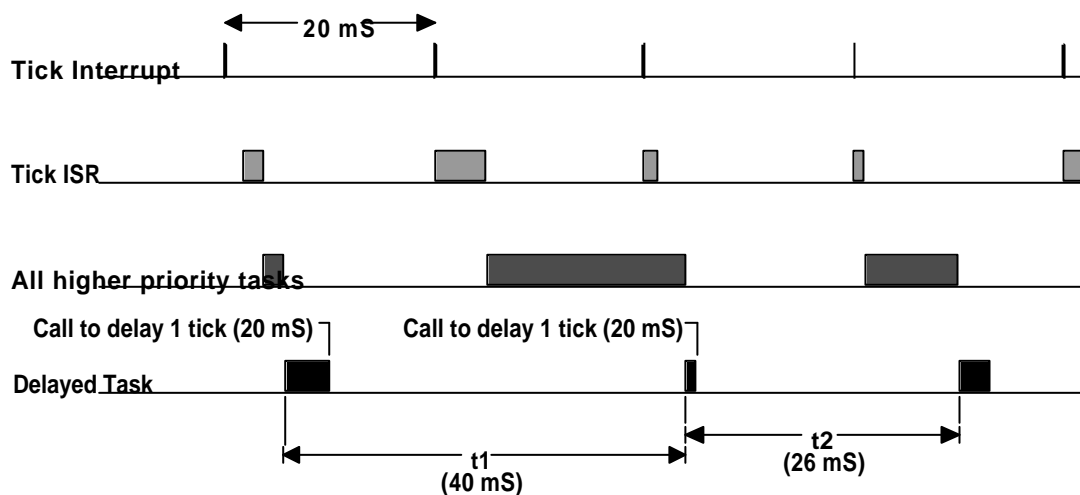
**Figure 2-24, Delaying a task for 1 tick (case #1).**

Case 2 (Figure 2-25) shows a situation where the execution times of all higher-priority tasks and ISRs are slightly less than one tick. If the task delays itself just before a clock tick, the task will execute again almost immediately! Because of this, if you need to delay a task for at least 1 clock tick, you must specify one extra tick. In other words, if you need to delay a task for at least 5 ticks, you must specify 6 ticks!



**Figure 2-25, Delaying a task for 1 tick (case #2).**

Case 3 (Figure 2-26) shows a situation where the execution times of all higher-priority tasks and ISRs extend beyond one clock tick. In this case, the task that tries to delay for 1 tick will actually execute 2 ticks later! In this case, the task missed its deadline. This might be acceptable in some applications, but in most cases it isn't.



**Figure 2-26, Delaying a task for 1 tick (case #3).**

These situations exist with all real-time kernels. They are related to CPU processing load and possibly incorrect system design. Here are some possible solutions to these problems:

- a) Increase the clock rate of your microprocessor.
- b) Increase the time between tick interrupts.
- c) Rearrange task priorities.
- d) Avoid using floating-point math (if you must, use single precision).
- e) Get a compiler that performs better code optimization.
- f) Write time-critical code in assembly language.
- g) If possible, upgrade to a faster microprocessor in the same family, e.g., 8086 to 80186, 68000 to 68020, etc.

Regardless of what you do, jitter will always occur.

## 2.34 Memory Requirements

If you are designing a foreground/background system, the amount of memory required depends solely on your application code.

With a multitasking kernel, things are quite different. To begin with, a kernel requires extra code space (ROM). The size of the kernel depends on many factors. Depending on the features provided by the kernel, you can expect anywhere from 1 Kbytes to 100 Kbytes. A minimal kernel for an 8-bit CPU that provides only scheduling, context switching, semaphore management, delays, and timeouts should require about 1 to 3 Kbytes of code space. The total code space is thus given by:

$$\text{Application code size} + \text{Kernel code size}$$

### Equation 2.12, Code space needed when a kernel is used.

Because each task runs independently of the other, each task must be provided with its own stack area (RAM). As a designer, you must determine the stack requirement of each task as closely as possible (this is sometimes a difficult undertaking). The stack size must not only account for the task requirements (local variables, function calls, etc.); the stack size must also account for maximum interrupt nesting (saved registers, local storage in ISRs, etc.). Depending on the target processor and the kernel used, a separate stack can be used to handle all interrupt-level code. This is a desirable feature because the stack requirement for each task can be substantially reduced. Another desirable feature is the ability to specify the stack size of each task on an individual basis ( $\mu$ C/OS-II permits this). Conversely, some kernels require that all task stacks be the same size. All kernels require extra RAM to maintain internal variables, data structures, queues, etc. The total RAM required if the kernel does not support a separate interrupt stack is given by:

$$\begin{aligned} &\text{Application code requirements} + \\ &\text{Data space (i.e. RAM) needed by the kernel} + \\ &\text{SUM(task stacks} + \text{MAX(ISR nesting))} \end{aligned}$$

### Equation 2.13, Data space needed when a kernel is used.

If the kernel supports a separate stack for interrupts, the total RAM required is given by:

$$\begin{aligned} &\text{Application code requirements} + \\ &\text{Data space (i.e. RAM) needed by the kernel} + \\ &\text{SUM(task stacks)} + \\ &\text{MAX(ISR nesting)} \end{aligned}$$

### Equation 2.13, Data space needed when a kernel is used.

Unless you have large amounts of RAM to work with, you will need to be careful about how you use the stack space. To reduce the amount of RAM needed in an application, you must be careful about how you use each task's stack for:

- a) large arrays and structures declared locally to functions and ISRs
- b) function (i.e., subroutine) nesting
- c) interrupt nesting
- d) library functions stack usage
- e) function calls with many arguments

To summarize, a multitasking system will require more code space (ROM) and data space (RAM) than a foreground/background system. The amount of extra ROM depends only on the size of the kernel, and the amount of RAM depends on the number of tasks in your system.

## 2.35 Advantages and Disadvantages of Real-Time Kernels

A real-time kernel, also called a *Real-Time Operating System*, or *RTOS*, allows realtime applications to be easily designed and expanded; functions can be added without requiring major changes to the software. The use of an RTOS simplifies the design process by splitting the application code into separate tasks. With a preemptive RTOS, all time-critical events are handled as quickly and as efficiently as possible. An RTOS allow you to make better use of your resources by providing you with precious services such as semaphores, mailboxes, queues, time delays, timeouts, etc.

You should consider using a real-time kernel if your application can afford the extra requirements: extra cost of the kernel, more ROM/RAM, and 2 to 4 percent additional CPU overhead.

The one factor I haven't mentioned so far is the cost associated with the use of a real-time kernel. In some applications, cost is everything and would preclude you from even considering an RTOS.

There are currently about 80+ RTOS vendors. Products are available for 8-, 16-, and 32-bit microprocessors. Some of these packages are complete operating systems and include not only the real-time kernel but also an input/output manager, windowing systems (display), a file system, networking, language interface libraries, debuggers, and cross-platform compilers. The cost of an RTOS varies from \$50 to well over \$30,000. The RTOS vendor may also require royalties on a per-target-system basis. This is like buying a chip from the RTOS vendor that you include with each unit sold. The RTOS vendors call this *silicon software*. The royalty fee varies between \$5 to about \$250 per unit. Like any other software package these days, you also need to consider the maintenance cost, which can set you back another \$100 to \$5,000 per year!

## 2.36 Real-Time Systems Summary

Table 2.2 summarizes the three types of real-time systems: foreground/background, non-preemptive kernel, and preemptive kernel.

	Foreground/Background	Non-Preemptive Kernel	Preemptive Kernel
<b>Interrupt latency (Time)</b>	MAX(Longest instruction, User int. disable) + Vector to ISR	MAX(Longest instruction, User int. disable, Kernel int. disable) + Vector to ISR	MAX(Longest instruction, User int. disable, Kernel int. disable) + Vector to ISR
<b>Interrupt response (Time)</b>	Int. latency + Save CPU's context	Int. latency + Save CPU's context	Interrupt latency + Save CPU's context + Kernel ISR entry function
<b>Interrupt recovery (Time)</b>	Restore background's context + Return from int.	Restore task's context + Return from int.	Find highest priority task + Restore highest priority task's context + Return from interrupt
<b>Task response (Time)</b>	Background	Longest task + Find highest priority task + Context switch	Find highest priority task + Context switch
<b>ROM size</b>	Application code	Application code + Kernel code	Application code + Kernel code
<b>RAM size</b>	Application code	Application code + Kernel RAM +	Application code + Kernel code + Application code + Kernel RAM +

		$SUM(Task\ stacks + MAX(ISR\ stack))$	$SUM(Task\ stacks + MAX(ISR\ stack))$
Services available?	Application code must provide	Yes	Yes

Table 2.2, Real-time systems summary.

## Chapter 3

# Kernel Structure

This chapter describes some of the structural aspects of  $\mu$  C/OS-II. You will learn:

- How  $\mu$  C/OS-II handles access to critical sections of code,
- What a task is, and how  $\mu$  C/OS-II knows about your tasks,
- How tasks are scheduled,
- How  $\mu$  C/OS-II can determine how much of CPU your application is using,
- How do to write Interrupt Service Routines (ISRs),
- What a clock tick is and how  $\mu$  C/OS-II handles it,
- How to initialize  $\mu$  C/OS-II and,
- How to start multitasking.

This chapter also describes the following application services:

- `OS_ENTER_CRITICAL()` and `OS_EXIT_CRITICAL()`,
- `OSInit()`,
- `OSStart()`,
- `OSIntEnter()` and `OSIntExit()`,
- `OSSchedLock()` and `OSSchedUnlock()` and,
- `OSVersion()`.

### 3.00 Critical Sections

$\mu$  C/OS-II like all real-time kernels need to disable interrupts in order to access critical sections of code, and re-enable interrupts when done. This allows  $\mu$  C/OS-II to protect critical code from being entered simultaneously from either multiple tasks or ISRs. The interrupt disable time is one of the most important specifications that a real-time kernel vendor can provide because it affects the responsiveness of your system to real-time events.  $\mu$  C/OS-II tries to keep the interrupt disable time to a minimum but, with  $\mu$  C/OS-II, interrupt disable time is largely dependent on the processor architecture, and the quality of the code generated by the compiler. Every processor generally provides instructions to disable/enable interrupts and your C compiler must have a mechanism to perform these operations directly from C. Some compilers will allow you to insert in-line assembly language statements in your C source code. This makes it quite easy to insert processor instructions to enable and disable interrupts. Other compilers will actually contain language extensions to enable and disable interrupts directly from C. To hide the implementation method chosen by the compiler manufacturer,  $\mu$  C/OS-II defines two macros to disable and enable interrupts: `OS_ENTER_CRITICAL()` and `OS_EXIT_CRITICAL()`, respectively. Because these macros are processor specific, they are found in a file called `OS_CPU.H`. Each processor port will thus have its own `OS_CPU.H` file.

Chapters 8, *Porting  $\mu$  C/OS-II* and chapter 9, *80x86, Large Model Port* provide additional details with regards to these two macros.

### 3.01 Tasks

A task is typically an infinite loop function L3.1(2) as shown in Listing 3.1. A task looks just like any other C function containing a return type and an argument but, it never returns. The return type must always be **void** L3.1(1).

```
void YourTask (void *pdata)                (1)
{
    for (;;) {                             (2)
        /* USER CODE */
        Call one of uC/OS-II's services:
        OSMboxPend();
        OSQPend();
        OSSemPend();
        OSTaskDel(OS_PRIO_SELF);
        OSTaskSuspend(OS_PRIO_SELF);
        OSTimeDly();
        OSTimeDlyHMSM();
        /* USER CODE */
    }
}
```

### Listing 3.1, A task is an infinite loop.

Alternatively, the task can delete itself upon completion as shown in Listing 3.2. Note that the task code is not actually deleted,  $\mu$  C/OS-II simply doesn't know about the task anymore and thus that code will not run. Also, if the task calls **OSTaskDel()**, the task code doesn't return back to anything.

```
void YourTask (void *pdata)
{
    /* USER CODE */
    OSTaskDel(OS_PRIO_SELF);
}
```

### Listing 3.2, A task that deletes itself when done.

The argument L3.1(1) is passed to your task code when the task first starts executing. You will notice that the argument is a pointer to a **void**. This allows your application to pass just about any kind of data to your task. The pointer is a 'universal' vehicle to pass to your task the address of a variable, a structure or even the address of a function if necessary! It is possible (see Example #1 in Chapter 1) to create many identical tasks all using the same function (or task body). For example, you could have 4 serial ports that are each managed by their own task. However, the task code is actually identical. Instead of copying the code 4 times, you can create a task that receives as an argument a pointer to a data structure that defines the serial port's parameters (baud rate, I/O port addresses, interrupt vector number, etc.).

$\mu$  C/OS-II can manage up to 64 tasks, however, the current version of  $\mu$  C/OS-II uses two tasks for system use. Also, I decided to reserve priorities 0, 1, 2, 3, **OS\_LOWEST\_PRIO-3**, **OS\_LOWEST\_PRIO-2**, **OS\_LOWEST\_PRIO-1** and **OS\_LOWEST\_PRIO** for future use. **OS\_LOWEST\_PRIO** is a **#define** constant which is defined in the file **OS\_CFG.H**. You can thus have up to 56 application tasks. Each task must be assigned a unique priority level from 0 to **OS\_LOWEST\_PRIO - 2**. The lower the priority number, the higher the priority of the task.  $\mu$  C/OS-II always executes the highest priority task ready to run. In the current version of  $\mu$  C/OS-II, the task priority number also serves as the task identifier. The priority number (i.e. task identifier) is used by some kernel services such as **OSTaskChangePrio()** and **OSTaskDel()**.

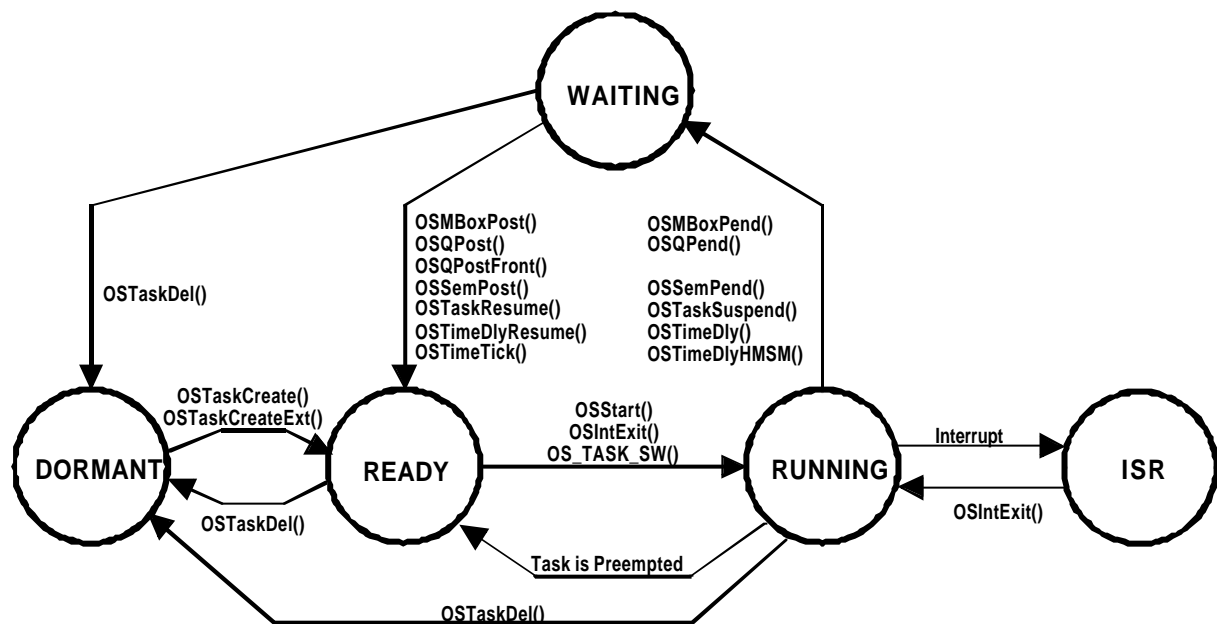
In order for  $\mu$  C/OS-II to manage your task, you must 'create' a task. You create a task by passing its address along with other arguments to one of two functions: **OSTaskCreate()** or **OSTaskCreateExt()**.



**OSTaskCreateExt()** is an 'extended' version of **OSTaskCreate()** and provides additional features. These two functions are explained in Chapter 4, *Task Management*.

### 3.02 Task States

Figure 3-1 shows the state transition diagram for tasks under  $\mu$ C/OS-II. At any given time, a task can be in any one of five states.



**Figure 3-1, Task States**

The **DORMANT** state corresponds to a task (see Listing 3.1 or Listing 3.2) which resides in program space (ROM or RAM) but has not been made available to  $\mu$ C/OS-II. A task is made available to  $\mu$ C/OS-II by calling either **OSTaskCreate()** or **OSTaskCreateExt()**. When a task is created, it is made **READY** to run. Tasks may be created before multitasking starts or dynamically by a running task. When created by a task, if the created task has a higher priority than its creator, the created task is immediately given control of the CPU. A task can return itself or another task to the dormant state by calling **OSTaskDel()**.

Multitasking is started by calling **OSStart()**. **OSStart()** runs the highest priority task that is **READY** to run. This task is thus placed in the **RUNNING** state. Only one task can be running at any given time. A ready task will not run until all higher priority tasks are either placed in the wait state or are deleted.

The running task may delay itself for a certain amount of time by either calling **OSTimeDly()** or **OSTimeDlyHMSM()**. This task is thus **WAITING** for some time to expire and the next highest priority task that is ready-to-run is immediately given control of the CPU. The delayed task is made ready to run by **OSTimeTick()** when the desired time delay expires (see Section 3.11, *Clock Tick*).

The running task may also need to wait until an event occurs, by calling either **OSSemPend()**, **OSMboxPend()** or **OSQPend()**. The task is thus **WAITING** for the occurrence of the event. When a task pends on an event, the next highest priority task is immediately given control of the CPU. The task is made ready when the event occurs. The occurrence of an event may be signaled by either another task or an ISR.

A running task can always be interrupted, unless the task or  $\mu$  C/OS-II disables interrupts. The task thus enters the *ISR* state. When an interrupt occurs, execution of the task is suspended and the ISR takes control of the CPU. The ISR may make one or more tasks ready to run by signaling one or more events. In this case, before returning from the ISR,  $\mu$  C/OS-II determines if the interrupted task is still the highest priority task ready to run. If a higher priority task is made ready to run by the ISR then the new highest priority task is resumed. Otherwise, the interrupted task is resumed.

When all tasks are either waiting for events or for time to expire then  $\mu$  C/OS-II executes the idle task, `OSTaskIdle()`.

### 3.03 Task Control Blocks (*OS\_TCBs*)

When a task is created, it is assigned a Task Control Block, **OS\_TCB** (see Listing 3.3). A task control block is a data structure that is used by  $\mu$  C/OS-II to maintain the state of a task when it is preempted. When the task regains control of the CPU the task control block allows the task to resume execution exactly where it left off. All **OS\_TCBs** reside in RAM. You will notice that I organized the fields in **OS\_TCB** to allow for data structure packing while maintaining a logical grouping of members. An **OS\_TCB** is initialized when a task is created (see Chapter 4, *Task Management*). Below is a description of each field in the **OS\_TCB** data structure.

```
typedef struct os_tcb {
    OS_STK          *OSTCBStkPtr;

#ifdef OS_TASK_CREATE_EXT_EN
    void            *OSTCBExtPtr;
    OS_STK          *OSTCBStkBottom;
    INT32U          OSTCBStkSize;
    INT16U          OSTCBOpt;
    INT16U          OSTCBId;
#endif

    struct os_tcb *OSTCBNext;
    struct os_tcb *OSTCBPrev;

#ifdef (OS_Q_EN && (OS_MAX_QS >= 2)) || OS_MBOX_EN || OS_SEM_EN
    OS_EVENT        *OSTCBEvtPtr;
#endif

#ifdef (OS_Q_EN && (OS_MAX_QS >= 2)) || OS_MBOX_EN
    void            *OSTCBMsg;
#endif

    INT16U          OSTCBDly;
    INT8U           OSTCBStat;
    INT8U           OSTCBPrio;

    INT8U           OSTCBX;
    INT8U           OSTCBY;
    INT8U           OSTCBBitX;
    INT8U           OSTCBBitY;

#ifdef OS_TASK_DEL_EN
    BOOLEAN         OSTCBDelReq;
#endif
} OS_TCB;
```

**Listing 3.3,  $\mu$  C/OS-II's Task Control Block**

**OSTCBStkPtr** contains a pointer to the current top of stack for the task.  $\mu$ C/OS-II allows each task to have its own stack but just as important, each stack can be of any size. Some commercial kernels assume that all stacks are the same size unless you write complex hooks. This limitation wastes RAM when all tasks have different stack requirements, because the largest anticipated stack size has to be allocated for all tasks. **OSTCBStkPtr** is the only field in the **OS\_TCB** data structure accessed from assembly language code (from the context switching code). Placing **OSTCBStkPtr** at the first entry in the structure makes accessing this field easier from assembly language code.

**OSTCBExtPtr** is a pointer to a user definable task control block extension. This allows you or the user of  $\mu$ C/OS-II to extend the task control block without having to change the source code for  $\mu$ C/OS-II. **OSTCBExtPtr** is only used by **OSTaskCreateExt()** and thus, you will need to set **OS\_TASK\_CREATE\_EXT\_EN** to 1 to enable this field. You could create a data structure that contains the name of each task, keep track of the execution time of the task, the number of times a task has been switched-in and more (see Example #3). Note that I decided to place this pointer immediately after the stack pointer in case you need to access this field from assembly language. This makes calculating the offset from the beginning of the data structure easier.

**OSTCBStkBottom** is a pointer to the task's stack bottom. If the processor's stack grows from high memory locations to low memory locations then **OSTCBStkBottom** will point at the lowest valid memory location for the stack. Similarly, if the processor's stack grows from low memory locations to high memory locations then **OSTCBStkBottom** will point at the highest valid stack address. **OSTCBStkBottom** is used by **OSTaskStkChk()** to check the size of a task's stack at run-time. This allows you determine the amount of free stack space available for each stack. Stack checking can only occur if you created a task with **OSTaskCreateExt()** and thus, you will need to set **OS\_TASK\_CREATE\_EXT\_EN** to 1 to enable this field.

**OSTCBStkSize** is a variable that holds the size of the stack in number of elements instead of bytes. This means that if a stack contains 1000 entries and each entry is 32-bit wide then the actual size of the stack is 4000 bytes. Similarly, a stack where entries are 16-bit wide would contain 2000 bytes for the same 1000 entries. **OSTCBStkSize** is used by **OSTaskStkChk()**. Again, this field is valid only if you set **OS\_TASK\_CREATE\_EXT\_EN** to 1.

**OSTCBOpt** is a variable that holds 'options' that can be passed to **OSTaskCreateExt()**. Because of this, this field is valid only if you set **OS\_TASK\_CREATE\_EXT\_EN** to 1.  $\mu$ C/OS-II currently only defines three options (see **uCOS\_II.H**): **OS\_TASK\_OPT\_STK\_CHK**, **OS\_TASK\_OPT\_STK\_CLR** and, **OS\_TASK\_OPT\_SAVE\_FP**. **OS\_TASK\_OPT\_STK\_CHK** is used to specify to **OSTaskCreateExt()** that stack checking is enabled for the task being created. **OS\_TASK\_OPT\_STK\_CLR** indicates that the stack needs to be cleared when the task is created. The stack only needs to be cleared if you intend to do stack checking. If you do not specify **OS\_TASK\_OPT\_STK\_CLR** and you create and delete tasks then, the stack checking will report incorrect stack usage. If you never delete a task once it's created and your startup code clears all RAM then, you can save valuable execution time by NOT specifying this option. Passing **OS\_TASK\_OPT\_STK\_CLR** will increase the execution time of **OSTaskCreateExt()** because it will clear the content of the stack. The larger you stack, the longer it will take. Finally, **OS\_TASK\_OPT\_SAVE\_FP** tells **OSTaskCreateExt()** that the task will be doing floating-point computations and, if the processor provides hardware assisted floating-point capability then, the floating-point registers will need to be saved for the task being created and during a context switch.

**OSTCBId** is a variable that is used to hold an identifier for the task. This field is currently not used and has only been included for future expansion.

**OSTCBNext** and **OSTCBPrev** are used to doubly link **OS\_TCBs**. This chain of **OS\_TCBs** is used by **OSTimeTick()** to update the **OSTCBDly** field for each task. The **OS\_TCB** for each task is linked when

the task is created and the **OS\_TCB** is removed from the list when the task is deleted. A doubly linked list is used to permit an element in the chain to be quickly inserted or removed.

**OSTCBEventPtr** is a pointer to an event control block and will be described later (see Chapter 6, *Intertask Communication & Synchronization*).

**OSTCBMsg** is a pointer to a message that is sent to a task. The use of this field will be described later (see Chapter 6, *Intertask Communication & Synchronization*).

**OSTCBDly** is used when a task needs to be delayed for a certain number of clock ticks or a task needs to pend for an event to occur with a timeout. In this case, this field contains the number of clock ticks that the task is allowed to wait for the event to occur. When this value is zero the task is not delayed or has no timeout when waiting for an event.

**OSTCBStat** contains the state of the task. When **OSTCBStat** is 0, the task is ready to run. Other values can be assigned to **OSTCBStat** and these values are described in **uCOS\_II.H**.

**OSTCBPrio** contains the task priority. A high priority task has a low **OSTCBPrio** value (that is, the lower the number, the higher the actual priority).

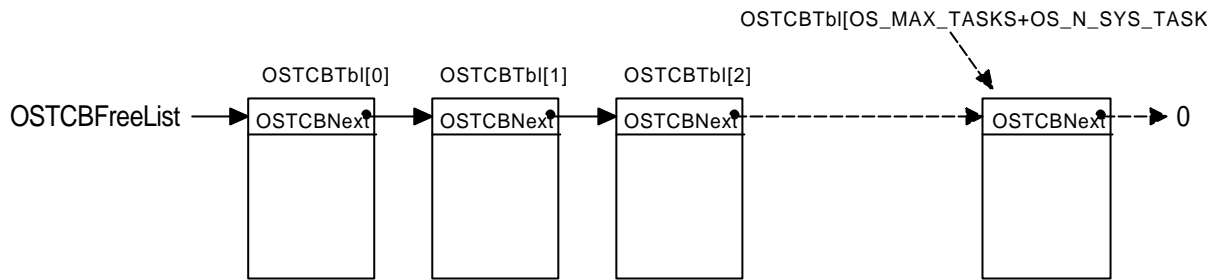
**OSTCBX**, **OSTCBY**, **OSTCBBitX** and **OSTCBBitY** are used to accelerate the process of making a task ready to run, or to make a task wait for an event (to avoid computing these values at runtime). The values for these fields are computed when the task is created or when the task's priority is changed. The values are obtained as follows:

```
OSTCBY      = priority >> 3;
OSTCBBitY   = OSMaTbl[priority >> 3];
OSTCBX      = priority & 0x07;
OSTCBBitX   = OSMaTbl[priority & 0x07];
```

### Listing 3.4, Calculating OS\_TCB members.

**OSTCBDeReq** is a boolean which is used to indicate whether or not a task requested that the current task be deleted. The use of this field will be described later (see Chapter 4, *Task Management*).

The maximum number of tasks (**OS\_MAX\_TASKS**) that an application can have is specified in **OS\_CFG.H** and determines the number of **OS\_TCBs** allocated by  $\mu$  C/OS-II for your application. You can reduce the amount of RAM needed by setting **OS\_MAX\_TASKS** to the number of actual tasks needed in your application. All **OS\_TCBs** are placed in **OSTCBTbl[ ]**. Note that  $\mu$  C/OS-II allocates **OS\_N\_SYS\_TASKS** (see **uCOS\_II.H**) extra **OS\_TCBs** for internal use. One will be used for the idle task while the other will be used for the statistic task (if **OS\_TASK\_STAT\_EN** is set to 1). When  $\mu$  C/OS-II is initialized, all **OS\_TCBs** in this table are linked in a singly linked list of free **OS\_TCBs** as shown in figure 3-2. When a task is created, the **OS\_TCB** pointed to by **OSTCBFreeList** is assigned to the task and, **OSTCBFreeList** is adjusted to point to the next **OS\_TCB** in the chain. When a task is deleted, its **OS\_TCB** is returned to the list of free **OS\_TCBs**.



**Figure 3-2, List of free OS\_TCBs**

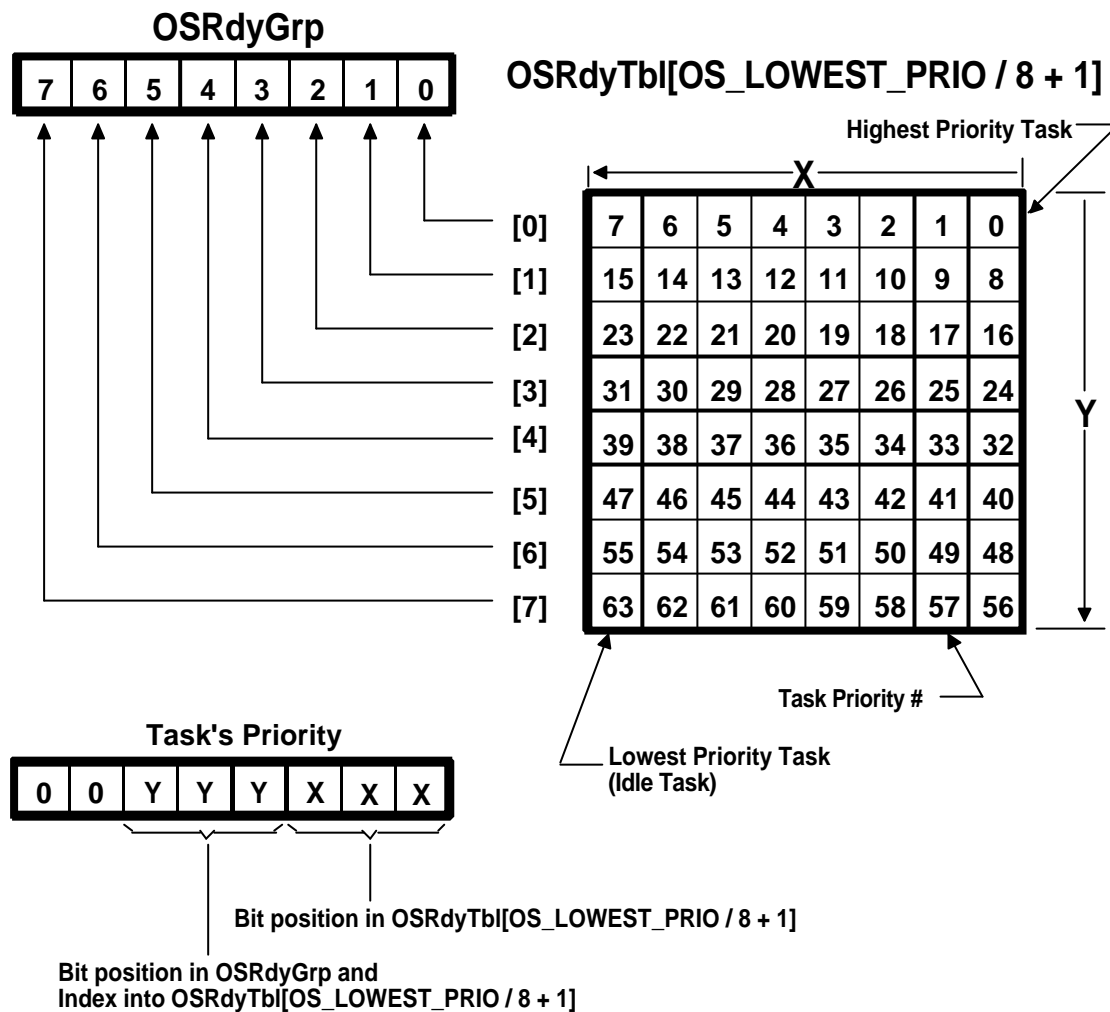
### 3.04 Ready List

Each task is assigned a unique priority level between 0 and **OS\_LOWEST\_PRIO**, inclusively (see **OS\_CFG.H**). Task priority **OS\_LOWEST\_PRIO** is always assigned to the idle task when  $\mu$ C/OS-II is initialized. You should note that **OS\_MAX\_TASKS** and **OS\_LOWEST\_PRIO** are unrelated. You can have only 10 tasks in an application while still having 32 priority levels (if you set **OS\_LOWEST\_PRIO** to 31).

Each task that is ready to run is placed in a ready list consisting of two variables, **OSRdyGrp** and **OSRdyTbl[ ]**. Task priorities are grouped (8 tasks per group) in **OSRdyGrp**. Each bit in **OSRdyGrp** is used to indicate whenever any task in a group is ready to run. When a task is ready to run it also sets its corresponding bit in the ready table, **OSRdyTbl[ ]**. The size of **OSRdyTbl[ ]** depends on **OS\_LOWEST\_PRIO** (see **uCOS\_II.H**). This allows you to reduce the amount of RAM (i.e. data space) needed by  $\mu$ C/OS-II when your application requires few task priorities.

To determine which priority (and thus which task) will run next, the scheduler determines the lowest priority number that has its bit set in **OSRdyTbl[ ]**. The relationship between **OSRdyGrp** and **OSRdyTbl[ ]** is shown in Figure 3-3 and is given by the following rules:

- Bit 0 in **OSRdyGrp** is 1 when any bit in **OSRdyTbl[ 0 ]** is 1.
- Bit 1 in **OSRdyGrp** is 1 when any bit in **OSRdyTbl[ 1 ]** is 1.
- Bit 2 in **OSRdyGrp** is 1 when any bit in **OSRdyTbl[ 2 ]** is 1.
- Bit 3 in **OSRdyGrp** is 1 when any bit in **OSRdyTbl[ 3 ]** is 1.
- Bit 4 in **OSRdyGrp** is 1 when any bit in **OSRdyTbl[ 4 ]** is 1.
- Bit 5 in **OSRdyGrp** is 1 when any bit in **OSRdyTbl[ 5 ]** is 1.
- Bit 6 in **OSRdyGrp** is 1 when any bit in **OSRdyTbl[ 6 ]** is 1.
- Bit 7 in **OSRdyGrp** is 1 when any bit in **OSRdyTbl[ 7 ]** is 1.



**Figure 3-3,  $\mu$ C/OS-II's Ready List**

The following piece of code is used to place a task in the ready list:

```
OSRdyGrp      |= OSMaPtbl[prio >> 3];
OSRdyTbl[prio >> 3] |= OSMaPtbl[prio & 0x07];
```

### **Listing 3.5, Making a task ready-to-run.**

where **prio** is the task's priority.

As you can see from Figure 3-3, the lower 3 bits of the task's priority are used to determine the bit position in **OSRdyTbl[ ]**, while the next three most significant bits are used to determine the index into **OSRdyTbl[ ]**. Note that **OSMaPtbl[ ]** (see **OS\_CORE.C**) is a table in ROM, used to equate an index from 0 to 7 to a bit mask as shown in the table below:

Index	Bit mask (Binary)
-------	-------------------

0	00000001
1	00000010
2	00000100
3	00001000
4	00010000
5	00100000
6	01000000
7	10000000

**Table 3.1, Contents of OSMapTbl[].**

A task is removed from the ready list by reversing the process. The following code is executed in this case:

```
if ((OSRdyTbl[prio >> 3] &= ~OSMapTbl[prio & 0x07]) == 0)
    OSRdyGrp &= ~OSMapTbl[prio >> 3];
```

### **Listing 3.6, Removing a task from the ready list.**

This code clears the ready bit of the task in **OSRdyTbl[]** and clears the bit in **OSRdyGrp** only if all tasks in a group are not ready to run, i.e. all bits in **OSRdyTbl[prio >> 3]** are 0. Another table lookup is performed, rather than scanning through the table starting with **OSRdyTbl[0]** to find the highest priority task ready to run. **OSUnMapTbl[256]** is a priority resolution table (see **OS\_CORE.C**). Eight bits are used to represent when tasks are ready in a group. The least significant bit has the highest priority. Using this byte to index the table returns the bit position of the highest priority bit set, a number between 0 and 7. Determining the priority of the highest priority task ready to run is accomplished with the following section of code:

```
y    = OSUnMapTbl[OSRdyGrp];
x    = OSUnMapTbl[OSRdyTbl[y]];
prio = (y << 3) + x;
```

### **Listing 3.7, Finding the highest priority task ready-to-run.**

For example, if **OSRdyGrp** contains 01101000 (binary) then the table lookup **OSUnMapTbl[OSRdyGrp]** would yield a value of 3, which corresponds to bit #3 in **OSRdyGrp**. Notes that bit positions are assumed to start on the right with bit #0 being the rightmost bit. Similarly, if **OSRdyTbl[3]** contained 11100100 (binary) then **OSUnMapTbl[OSRdyTbl[3]]** would result in a value of 2 (i.e. bit #2). The task priority (**prio**) would then be 26 ( $3 * 8 + 2$ )! Getting a pointer to the **OS\_TCB** for the corresponding task is done by indexing into **OSTCBPrioTbl[]** using the task's priority.

## **3.05 Task Scheduling**

μC/OS-II always executes the highest priority task ready to run. The determination of which task has the highest priority and thus, which task will be next to run is determined by the scheduler. Task level scheduling is performed by **OSSched()**. ISR level scheduling is handled by another function (**OSIntExit()**) and will be described later. The code for **OSSched()** is shown in Listing 3.8.

μC/OS-II's task scheduling time is constant irrespective of the number of tasks created in an application. **OSSched()** exits if called from an ISR (i.e. **OSIntNesting > 0**) or if scheduling has been disabled because your application called **OSSchedLock()** at least once (i.e. **OSLockNesting > 0**) L3.8(1). If **OSSched()** is not called from an ISR and the scheduler is enabled then **OSSched()** determines the priority of the highest priority task that is ready to run L3.8(2). A task that is ready to run has its corresponding bit set in **OSRdyTbl[]**. Once the highest priority task has been found, **OSSched()** verifies that the highest priority task is not the current task. This is done to avoid an

unnecessary context switch L3.8(3). Note that  $\mu$  C/OS used to obtain **OSTCBHighRdy** and compared it with **OSTCBCur**. On 8 and some 16-bit processors, this operation was relatively slow because comparison was made on pointers instead of 8-bit integers as it is now done in  $\mu$  C/OS-II. Also, there is no point of looking up **OSTCBHighRdy** in **OSTCBPrioTbl[]** unless we actually need to do a context switch. The combination of comparing 8-bit values instead of pointers and looking up **OSTCBHighRdy** only when needed should make  $\mu$  C/OS-II faster than  $\mu$  C/OS on 8 and some 16-bit processors.

```
void OSSched (void)
{
    INT8U y;

    OS_ENTER_CRITICAL();
    if ((OSLockNesting | OSIntNesting) == 0) {
        y = OSUnMapTbl[OSRdyGrp];
        OSPrioHighRdy = (INT8U)((y << 3) + OSUnMapTbl[OSRdyTbl[y]]);
        if (OSPrioHighRdy != OSPrioCur) {
            OSTCBHighRdy = OSTCBPrioTbl[OSPrioHighRdy];
            OSctxSwCtr++;
            OS_TASK_SW();
        }
    }
    OS_EXIT_CRITICAL();
}
```

### Listing 3.8, Task Scheduler

To perform a context switch, we need to have **OSTCBHighRdy** point to the **OS\_TCB** of the highest priority task which is done by indexing into **OSTCBPrioTbl[]** using **OSPrioHighRdy** L3.8(4). Next, the statistic counter **OSctxSwCtr** is incremented to keep track of the number of context switches L3.8(5). Finally, the macro **OS\_TASK\_SW()** is invoked to do the actual context switch L3.8(6).

A context switch simply consist of saving the processor registers on the stack of the task being suspended, and restoring the registers of the higher-priority task from its stack. In  $\mu$  C/OS-II, the stack frame for a ready task always looks as if an interrupt has just occurred and all processor registers were saved onto it. In other words, all that  $\mu$  C/OS-II has to do to run a ready task is to restore all processor registers from the task's stack and execute a return from interrupt. To switch context, you should implement **OS\_TASK\_SW()** so that you simulate an interrupt. Most processors provide either software interrupt or **TRAP** instructions to accomplish this. The interrupt service routine (ISR) or trap handler (also called the 'exception handler') MUST vector to the assembly language function **OSctxSw()**. **OSctxSw()** expects to have **OSTCBHighRdy** point to the **OS\_TCB** of the task to switch in and **OSTCBCur** point to the **OS\_TCB** of the task being suspended. Refer to chapter 8, *Porting  $\mu$  C/OS-II* for additional details on **OSctxSw()**.

All of the code in **OSSched()** is considered a critical section. Interrupts are disabled to prevent ISRs from setting the ready bit of one or more tasks during the process of finding the highest priority task ready to run. Note that **OSSched()** could be written entirely in assembly language to reduce scheduling time. **OSSched()** was written in C for readability, portability and also to minimize assembly language.

### 3.06 Locking and Unlocking the Scheduler

The **OSSchedLock()** function is used to prevent task rescheduling until its counterpart, **OSSchedUnlock()**, is called. The code for these functions is shown in Listing 3.9 and 3.10. The task that calls **OSSchedLock()** keeps control of the CPU even though other higher priority tasks are ready to run. Interrupts, however, are still recognized



and serviced (assuming interrupts are enabled). **OSSchedLock()** and **OSSchedUnlock()** must be used in pairs. The variable **OSLockNesting** keeps track of the number of times **OSSchedLock()** has been called to allow for nesting. This allows nested functions which contain critical code that other tasks cannot access.  $\mu$ C/OS-II allows nesting up to 255 levels deep. Scheduling is re-enabled when **OSLockNesting** is 0. **OSSchedLock()** and **OSSchedUnlock()** must be used with caution because they affect the normal management of tasks by  $\mu$ C/OS-II.

**OSSchedUnlock()** calls the scheduler L3.10(2) when **OSLockNesting** has decremented to 0 L3.10(1) and **OSSchedUnlock()** is called from a task, because events could have made higher priority tasks ready to run while scheduling was locked.

After calling **OSSchedLock()**, your application must not make any system call that will suspend execution of the current task, i.e., your application cannot call **OSMboxPend()**, **OSQPend()**, **OSSemPend()**, **OSTaskSuspend(OS\_PRIO\_SELF)**, **OSTimeDly()** or **OSTimeDlyHMSM()** until **OSLockNesting** returns to 0. No other task will be allowed to run, because the scheduler is locked out and your system will lock up.

```
void OSSchedLock (void)
{
    if (OSRunning == TRUE) {
        OS_ENTER_CRITICAL();
        OSLockNesting++;
        OS_EXIT_CRITICAL();
    }
}
```

### Listing 3.9, Locking the Scheduler

```
void OSSchedUnlock (void)
{
    if (OSRunning == TRUE) {
        OS_ENTER_CRITICAL();
        if (OSLockNesting > 0) {
            OSLockNesting--;
            if ((OSLockNesting | OSIntNesting) == 0) {          (1)
                OS_EXIT_CRITICAL();
                OSSched();                                       (2)
            } else {
                OS_EXIT_CRITICAL();
            }
        } else {
            OS_EXIT_CRITICAL();
        }
    }
}
```

### Listing 3.10, Unlocking the Scheduler

You may want to disable the scheduler when a low priority task needs to post messages to multiple mailboxes, queues or semaphores (see Chapter 6, *Intertask Communication & Synchronization*) and you don't want a higher priority task to take control until all mailboxes, queues and semaphores have been posted to.

## 3.07 Idle Task

$\mu$ C/OS-II always creates a task (a.k.a. the *Idle Task*) which is executed when none of the other tasks is ready to run. The idle task (**OSTaskIdle()**) is always set to the lowest priority, i.e. **OS\_LOWEST\_PRIO**. **OSTaskIdle()** does nothing but increment a 32-bit counter called **OSIdleCtr**. **OSIdleCtr** is used by the statistics task (see Section 3.08, *Statistic Task*) to determine how much CPU time (in percentage) is actually being consumed by the application software. The code for the idle task is shown below. Interrupts are disabled then enabled around the increment because on 8-bit and most 16-bit processors, a 32-bit increment requires multiple instructions which must be protected from being accessed by higher priority tasks or an ISR. The idle task can never be deleted by application software.

```
void OSTaskIdle (void *pdata)
{
    pdata = pdata;
    for (;;) {
        OS_ENTER_CRITICAL();
        OSIdleCtr++;
        OS_EXIT_CRITICAL();
    }
}
```

**Listing 3.10,  $\mu$ C/OS-II's Idle task.**

### 3.08 Statistics Task

$\mu$ C/OS-II contains a task that provides run-time statistics. This task is called **OSTaskStat()** and is created if you set the configuration constant **OS\_TASK\_STAT\_EN** (see **OS\_CFG.H**) to 1. When enabled, **OSTaskStat()** (see **OS\_CORE.C**) executes every second and computes the percentage of CPU usage. In other words, **OSTaskStat()** will tell you how much of the CPU time is used by your application, in percentage. This value is placed in the variable **OSCPUUsage** which is a signed 8-bit integer. The resolution of **OSCPUUsage** is 1%.

If your application is to use the statistic task, you **MUST** call **OSStatInit()** (see **OS\_CORE.C**) from the first and only task created in your application during initialization. In other words, your startup code **MUST** create only one task before calling **OSStart()**. From this one task, you **MUST** call **OSStatInit()** before you create your other application tasks. The pseudo-code below shows what needs to be done.

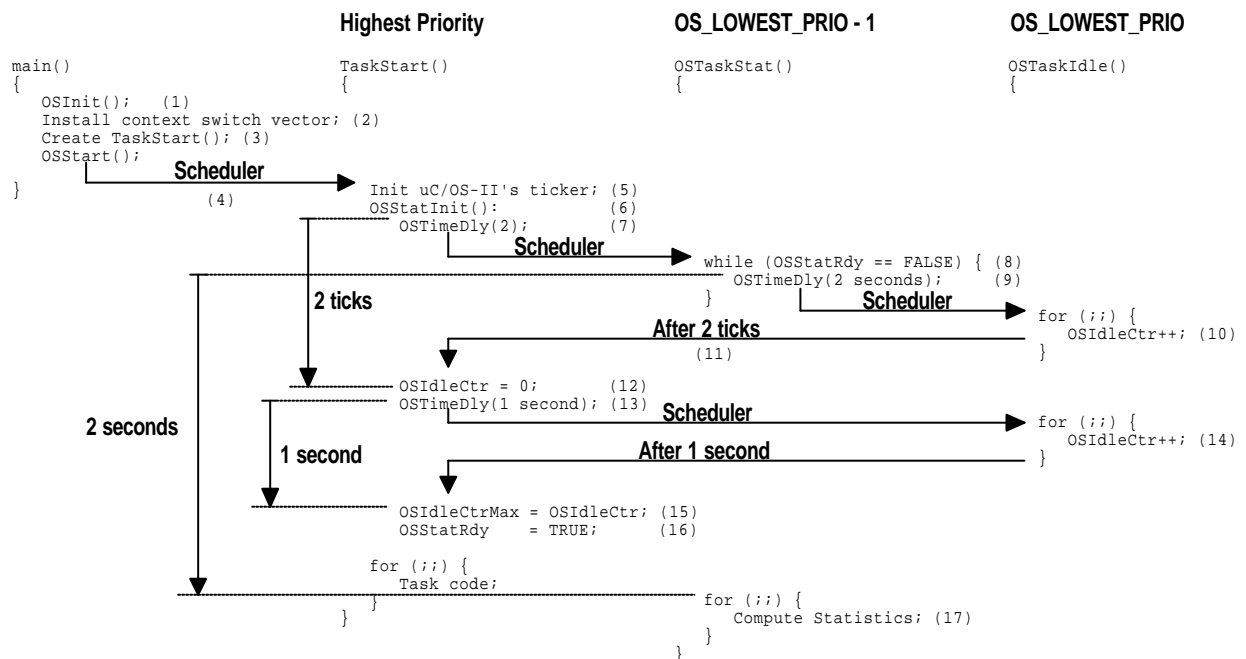
```
void main (void)
{
    OSInit();                /* Initialize uC/OS-II                (1)*/
    /* Install uC/OS-II's context switch vector                */
    /* Create your startup task (for sake of discussion, TaskStart()) (2)*/
    OSStart();                /* Start multitasking                (3)*/
}

void TaskStart (void *pdata)
{
    /* Install and initialize  $\mu$ C/OS-II's ticker                (4)*/
    OSStatInit();             /* Initialize statistics task        (5)*/
    /* Create your application task(s)                        */
    for (;;) {
        /* Code for TaskStart() goes here!                    */
    }
}
```

**Listing 3.11, Initializing the statistic task.**

Because I mentioned that your application must create only one task (i.e. **TaskStart()**),  $\mu$  C/OS-II has only three tasks to manage when **main()** calls **OSStart(): TaskStart(), OSTaskIdle()** and **OSTaskStat()**. Please note that you don't have to call the startup task **TaskStart()** – you can call it anything you like. Your startup task will have the highest priority because  $\mu$  C/OS-II sets the priority of the idle task to **OS\_LOWEST\_PRIO** and the priority of the statistic task to **OS\_LOWEST\_PRIO - 1** internally.

Figure 3-4 illustrates the flow of execution when initializing the statistic task. The first function that you must call in  $\mu$  C/OS-II is **OSInit()** which will initialize  $\mu$  C/OS-II F3-4(1). Next, you need to install the interrupt vector that will be used to perform context switches F3-4(2). Note that on some processors (specifically the Motorola 68HC11), there is no need to ‘install’ a vector because the vector would already be resident in ROM. You must create **TaskStart()** by calling either **OSTaskCreate()** or **OSTaskCreateExt()** F3-4(3). Once you are ready to multitask, you call **OSStart()** which will schedule **TaskStart()** for execution because it has the highest priority F3-4(4).



### Figure 3-4, Statistic task initialization

**TaskStart()** is responsible for initializing and starting the ticker F3-4(5). This is necessary because we don't want to receive a tick interrupt until we are actually multitasking. Next, **TaskStart()** calls **OSStatInit()** F3-4(6). **OSStatInit()** determines how high the idle counter (**OSIdleCtr**) can count up to if no other task in the application is executing. A Pentium-II running at 333 MHz increments this counter to a value of 15,000,000 or so. **OSIdleCtr** is still far from wrapping around the 4,294,967,296 limit of a 32-bit value. As processors get faster, you may want to keep an eye on this potential problem.

**OSStatInit()** starts off by calling **OSTimeDly()** F3-4(7) which will put **TaskStart()** to sleep for two ticks. This is done to synchronize **OSStatInit()** to the ticker.  $\mu$  C/OS-II will then pick the next highest priority task that is ready to run, which happens to be **OSTaskStat()**. We will see the code for **OSTaskStat()** later but, as a preview, the very first thing **OSTaskStat()** does is check to see if the flag **OSStatRdy** is set to **FALSE** F3-4(8)

and delays for 2 seconds if it is. It so happens that **OSStatRdy** is initialized to **FALSE** by **OSInit()** and thus, **OSTaskStat()** will in fact put itself to sleep for 2 seconds F3-4(9). This causes a context switch to the only task that is ready to run, **OSTaskIdle()**. The CPU stays in **OSTaskIdle()** F3-4(10) until the two ticks of **TaskStart()** expire. After two ticks, **TaskStart()** resumes F3-4(11) execution in **OSStatInit()** and **OSIdleCtr** is cleared F3-4(12). Then, **OSStatInit()** delays itself for one full second F3-4(13). Because no other task is ready to run, **OSTaskIdle()** will again get control of the CPU. During that time, **OSIdleCtr** will be continuously incremented F3-4(14). After one second, **TaskStart()** is resumed, still in **OSStatInit()** and, the value that **OSIdleCtr** reached during that one second is saved in **OSIdleCtrMax** F3-4(15). **OSStatInit()** sets **OSStatRdy** to **TRUE** F3-4(16) which will allow **OSTaskStat()** to perform CPU usage computation F3-4(17) after its delay of 2 seconds expires.

The actual code for **OSStatInit()** is shown below.

```
void OSStatInit (void)
{
    OSTimeDly(2);
    OS_ENTER_CRITICAL();
    OSIdleCtr      = 0L;
    OS_EXIT_CRITICAL();
    OSTimeDly(OS_TICKS_PER_SEC);
    OS_ENTER_CRITICAL();
    OSIdleCtrMax = OSIdleCtr;
    OSStatRdy    = TRUE;
    OS_EXIT_CRITICAL();
}
```

### Listing 3.12, Initializing the statistic task.

The code for **OSTaskStat()** is shown in listing 3.13. We already discussed why we have to wait for **OSStatRdy** in the previous paragraphs L3.13(1). The task code executes every second and basically determines how much CPU time is actually consumed by all the application tasks. When you start adding application code, the idle task will get less of the processor's time and thus, **OSIdleCtr** will not be allowed to count as high as it did when nothing else was running. Remember that we save this maximum value in **OSIdleCtrMax**. CPU utilization is stored in the variable **OSCPUUsage** and is computed L3.13(2) as follows:

$$OSCPUUsage_{(\%)} = 100 \times \left( 1 - \frac{OSIdleCtr}{OSIdleCtrMax} \right)$$

Once the above computation is performed, **OSTaskStat()** calls **OSTaskStatHook()** L3.13(3) which is a user definable function that allows for the statistic task to be expanded. Indeed, your application could compute and display the total execution time of all the tasks, what percentage of time is actually consumed by each task, and more (see *Example #3*).

```
void OSTaskStat (void *pdata)
{
    INT32U run;
    INT8S  usage;

    pdata = pdata;
    while (OSStatRdy == FALSE) {
        OSTimeDly(2 * OS_TICKS_PER_SEC);
    }
}
```

```

for (;;) {
    OS_ENTER_CRITICAL();
    OSIdleCtrRun = OSIdleCtr;
    run         = OSIdleCtr;
    OSIdleCtr    = 0L;
    OS_EXIT_CRITICAL();
    if (OSIdleCtrMax > 0L) {
        usage = (INT8S)(100L - 100L * run / OSIdleCtrMax);    (2)
        if (usage > 100) {
            OSCPUUsage = 100;
        } else if (usage < 0) {
            OSCPUUsage = 0;
        } else {
            OSCPUUsage = usage;
        }
    } else {
        OSCPUUsage = 0;
    }
    OSTaskStatHook();                                         (3)
    OSTimeDly(OS_TICKS_PER_SEC);
}
}

```

**Listing 3.13, Statistics Task.**

### ***3.09 Interrupts under $\mu$ C/OS-II***

$\mu$ C/OS-II requires that an Interrupt Service Routine (ISR) be written in assembly language. If your C compiler supports in-line assembly language, however, you can put the ISR code directly in a C source file. The pseudo code for an ISR is shown below:

```

YourISR:
    Save all CPU registers;                                (1)
    Call OSIntEnter() or, increment OSIntNesting directly; (2)
    Execute user code to service ISR;                      (3)
    Call OSIntExit();                                     (4)
    Restore all CPU registers;                             (5)
    Execute a return from interrupt instruction;           (6)

```

### Listing 3.14, ISRs under $\mu$ C/OS-II.

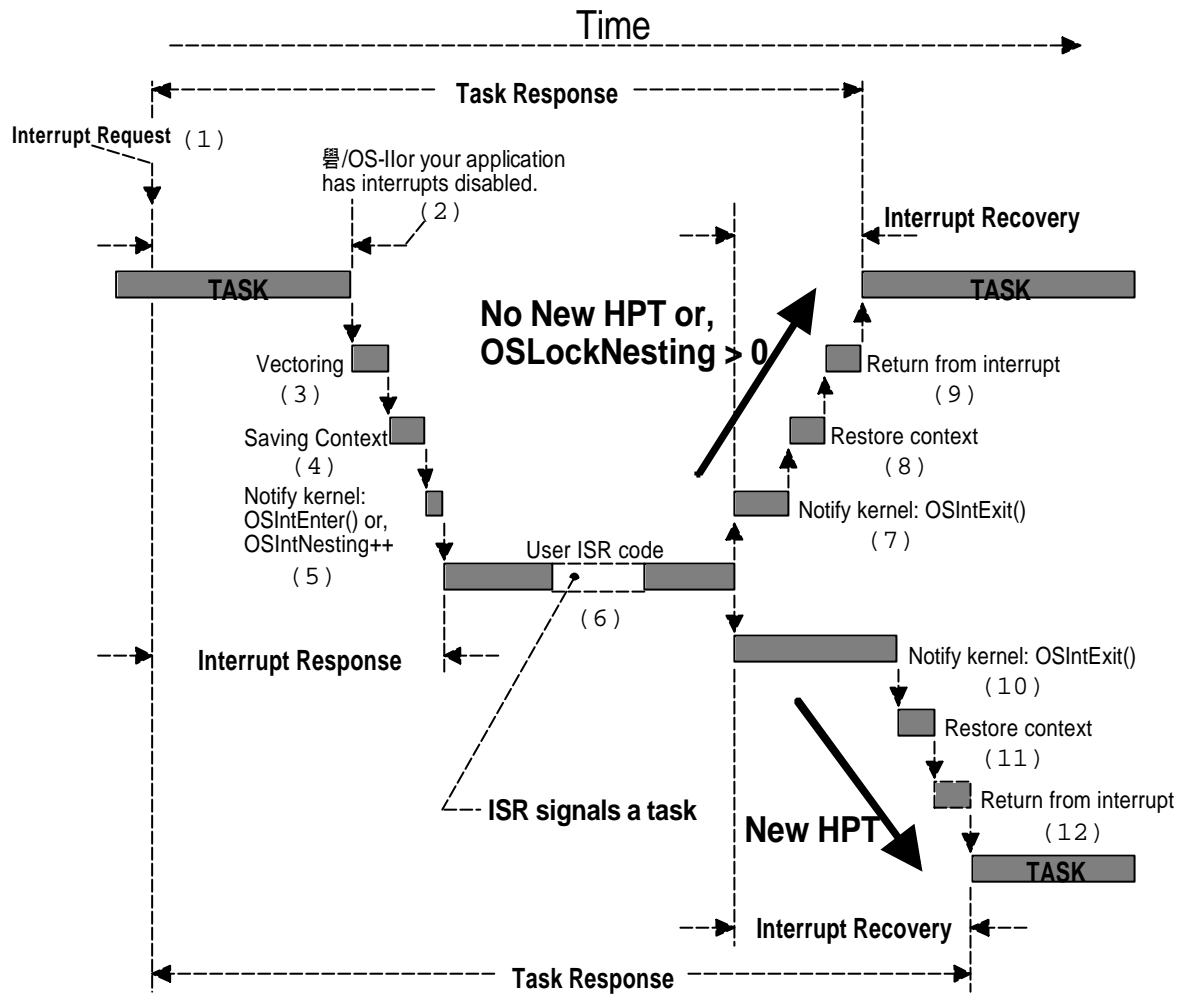
Your code should save all CPU registers onto the current task stack L3.14(1). Note that on some processors like the Motorola 68020 (and higher), however, a different stack is used when servicing an interrupt.  $\mu$  C/OS-II can work with such processors as long as the registers are saved on the interrupted task's stack when a context switch occurs.

$\mu$  C/OS-II needs to know that you are servicing an ISR and thus, you need to either call **OSIntEnter()** or, increment the global variable **OSIntNesting** L3.14(2). **OSIntNesting** can be incremented directly if your processor performs an increment operation to memory using a single instruction. If your processor forces you to read **OSIntNesting** in a register, increment the register and then store the result back in **OSIntNesting** then you should call **OSIntEnter()**. **OSIntEnter()** wraps these three instructions with code to disable and then enable interrupts thus ensuring access to **OSIntNesting** which is considered a shared resource. Incrementing **OSIntNesting** directly is much faster than calling **OSIntEnter()** and is thus the preferred way. One word of caution, some implementation of **OSIntEnter()** will cause interrupts to be enabled when **OSIntEnter()** returns. In these cases, you will need to clear the interrupt source before calling **OSIntEnter()** because otherwise, your interrupt will be re-entered continuously and your application will crash!

Once the previous two steps have been accomplished, you can start servicing the interrupting device L3.14(3). This section is obviously application specific.  $\mu$  C/OS-II allows you to nest interrupts because it keeps track of nesting in **OSIntNesting**. In most cases, however, you will need to clear the interrupt source before you enable interrupts to allow for interrupt nesting.

The conclusion of the ISR is marked by calling **OSIntExit()** L3.14(4) which decrements the interrupt nesting counter. When the nesting counter reaches 0, all nested interrupts have completed and  $\mu$  C/OS-II needs to determine whether a higher priority task has been awakened by the ISR (or any other nested ISR). If a higher priority task is ready to run,  $\mu$  C/OS-II will return to the higher priority task rather than to the interrupted task. If the interrupted task is still the most important task to run the **OSIntExit()** will return to its caller L3.14(5). At that point the saved registers are restored and a return from interrupt instruction is executed L3.14(6). Note that  $\mu$  C/OS-II will return to the interrupted task if scheduling has been disabled (**OSLockNesting** > 0).

The above description is further illustrated in figure 3-5. The interrupt is received F3-5(1) but is not recognized by the CPU either because interrupts have been disabled by  $\mu$  C/OS-II or your application or, the CPU has not completed executing the current instruction. Once the CPU recognizes the interrupt F3-5(2), the CPU vectors (at least on most microprocessors) to the ISR F3-5(3). As described above, the ISR saves the CPU registers F3-5(4) (i.e. the CPU's context). Once this is done, your ISR notifies  $\mu$  C/OS-II by calling **OSIntEnter()** or by incrementing **OSIntNesting** F3-5(5). Your ISR code then gets to execute F3-5(6). Your ISR should do as little work as possible and defer most of the work to the task. A task is notified of the ISR by calling either **OSMboxPost()**, **OSQPost()** or **OSSemPost()**. The receiving task may or may not be pending at the mailbox, queue or semaphore when the ISR occurs and the post is made. Once the user ISR code has completed, your need to call **OSIntExit()** F3-5(7). As can be seen from the timing diagram, **OSIntExit()** takes less time to return to the interrupted task when there is no higher priority task (HPT) readied by the ISR. Furthermore, in this case, the CPU registers are then simply restored F3-5(8) and a return from interrupt instruction is executed F3-5(9). If the ISR made a higher priority task ready to run then **OSIntExit()** will take longer to execute since a context switch is now needed F3-5(10). The registers of the new task will be restored F3-5(11) and a return from interrupt instruction will be executed F3-5(12).



**Figure 3-5, Servicing an interrupt**

The code for `OSIntEnter()` is shown in listing 3.15 and the code for `OSIntExit()` is shown in listing 3.16. Very little needs to be said about `OSIntEnter()`.

```

void OSIntEnter (void)
{
    OS_ENTER_CRITICAL();
    OSIntNesting++;
    OS_EXIT_CRITICAL();
}

```

**Listing 3.15, Notify  $\mu$ C/OS-II about beginning of ISR.**

```

void OSIntExit (void)
{
    OS_ENTER_CRITICAL();
    if ((--OSIntNesting | OSLockNesting) == 0) {
        OSIntExitY = OSUnMapTbl[OSRdyGrp];
        OSPrioHighRdy = (INT8U)((OSIntExitY << 3) +
                                OSUnMapTbl[OSRdyTbl[OSIntExitY]]);
        if (OSPrioHighRdy != OSPrioCur) {
            OSTCBHighRdy = OSTCBPrioTbl[OSPrioHighRdy];
            OSCtxSwCtr++;
            OSIntCtxSw();
        }
    }
    OS_EXIT_CRITICAL();
}

```

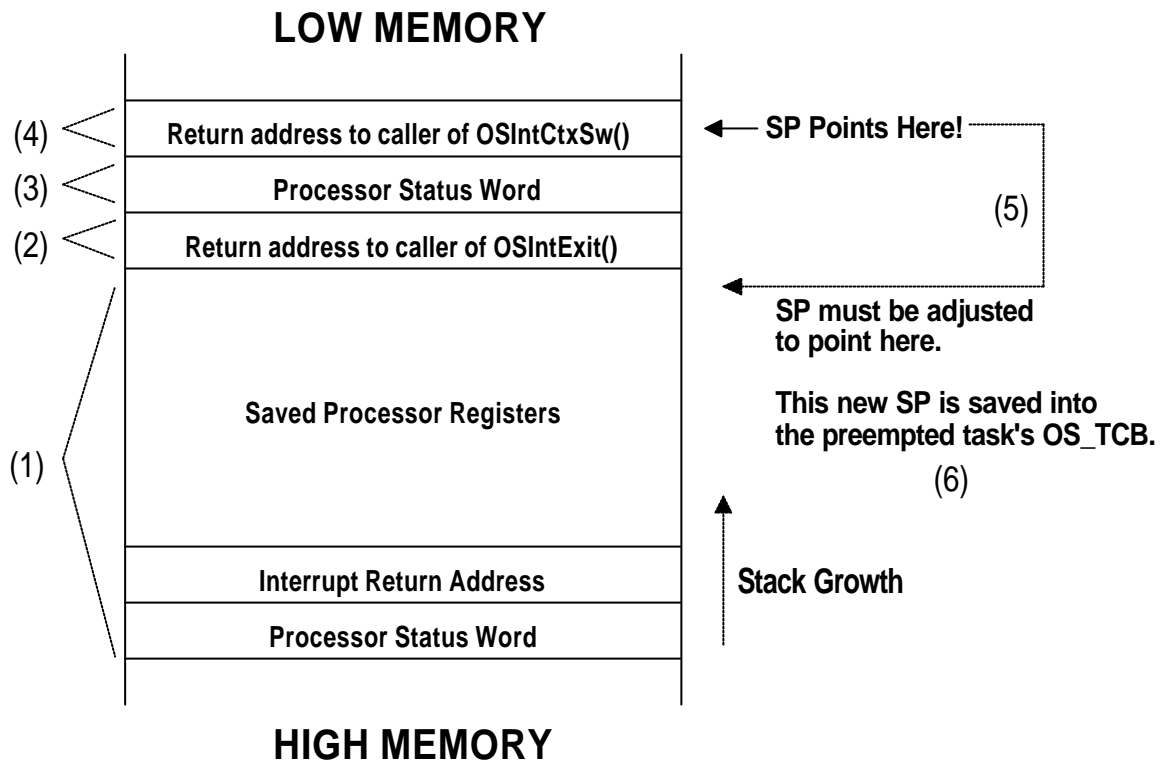
**Listing 3.16, Notify  $\mu$  C/OS-II about leaving an ISR.**

**OSIntExit()** looks strangely like **OSSched()** except for three differences. First the interrupt nesting counter is decremented in **OSIntExit()** L3.16(2) and rescheduling occurs when both the interrupt nesting counter and the lock nesting counter (**OSLockNesting**) are both 0. The second difference is that the Y index needed for **OSRdyTbl[]** is stored in the global variable **OSIntExitY** L3.16(3). This is done to avoid allocating a local variable on the stack which, would need to be accounted for in **OSIntCtxSw()** (see Section 9.04.03, *OS\_CPU\_A.ASM, OSIntCtxSw()*). Finally, If a context switch is needed, **OSIntExit()** calls **OSIntCtxSw()** L3.16(4) instead of **OS\_TASK\_SW()** as it did in **OSSched()**.

There are two reasons for calling **OSIntCtxSw()** instead of **OS\_TASK\_SW()**. First, half the work is already done because the ISR has already saved the CPU registers onto the task stack as shown in L3.14(1) and F3-6(1). Second, calling **OSIntExit()** from the ISR pushes the return address of the ISR onto the stack L3.14(4) and F3-6(2). Depending on how interrupts are disabled (see Chapter 9, *Porting  $\mu$  C/OS-II*), the processor's status word may be pushed onto the stack L3.16(1) and F3-6(3) by **OS\_ENTER\_CRITICAL()** in **OSIntExit()**. Finally, the return address of the call to **OSIntCtxSw()** is also pushed onto the stack L3.16(4) and F3-6(4). The stack frame looks like what  $\mu$  C/OS-II expects when a task is suspended except for the extra elements on the stack F3-6(2), F3-6(3) and F3-6(4). **OSIntCtxSw()** simply needs to adjust the processor's stack pointer as shown in F3-6(5). In other words, adjusting the stack frame ensures that all the stack frames of the suspended tasks look the same.

Implementation details about **OSIntCtxSw()** are provided in chapter 9, *Porting  $\mu$  C/OS-II*.





**Figure 3-6, Cleanup by OSIntCtxSw().**

Some processors like the Motorola 68HC11 require that you implicitly re-enable interrupts in order to allow for nesting. This can be used to your advantage. Indeed, if your ISR needs to be serviced quickly and the ISR doesn't need to notify a task about the ISR then, you don't need to call **OSIntEnter()** (or increment **OSIntNesting**) nor **OSIntExit()** as long as you don't enable interrupts within the ISR. The pseudo-code below shows this situation. The only way a task and this ISR can communicate is through global variables.

```
M68HC11_ISR:                /* Fast ISR, MUST NOT enable interrupts */
    All register saved automatically by ISR;
    Execute user code to service ISR;
    Execute a return from interrupt instruction;
```

**Listing 3.17, ISRs on a Motorola 68HC11.**

### 3.10 Clock Tick

$\mu$ C/OS-II requires that you provide a periodic time source to keep track of time delays and timeouts. A tick should occur between 10 and 100 times per second, or Hertz. The faster the tick rate, the higher the overhead imposed on the system. The actual frequency of the clock tick depends on the desired tick resolution of your application. You can obtain a tick source by either dedicating a hardware timer, or generating an interrupt from an AC power line (50/60 Hz) signal.

You MUST enable ticker interrupts AFTER multitasking has started, i.e. after calling `OSStart()`. In other words, you should initialize and tick interrupts in the first task that executes following a call to `OSStart()`. A common mistake is to enable ticker interrupts between calling `OSInit()` and `OSStart()` as shown in listing 3.18.

```
void main(void)
{
    .
    .
    OSInit();                /* Initialize  $\mu$ C/OS-II          */
    .
    .
    /* Application initialization code ...                */
    /* ... Create at least on task by calling OSTaskCreate() */
    .
    .
    Enable TICKER interrupts; /* DO NOT DO THIS HERE!!!    */
    .
    .
    OSStart();              /* Start multitasking      */
    .
}
```

#### Listing 3.18, Incorrect way to start the ticker.

What could happen (and it has happened) is that the tick interrupt could be serviced before  $\mu$ C/OS-II starts the first task. At this point,  $\mu$ C/OS-II is in an unknown state and will cause your application to crash.

$\mu$ C/OS-II's clock tick is serviced by calling `OSTimeTick()` from a *tick ISR*. The tick ISR follows all the rules described in the previous section. The pseudo code for the tick ISR is shown in listing 3.19. This code must be written in assembly language because you cannot access CPU registers directly from C.

```

void OSTickISR(void)
{
    Save processor registers;
    Call OSIntEnter() or increment OSIntNesting;

    Call OSTimeTick();

    Call OSIntExit();
    Restore processor registers;
    Execute a return from interrupt instruction;
}

```

### Listing 3.19, Pseudo code for Tick ISR.

The code for **OSTimeTick()** is shown in listing 3.20. **OSTimeTick()** starts by calling a user definable function (**OSTimeTickHook()**) which can be used to extend the functionality of **OSTimeTick()** L3.20(1). I decided to call **OSTimeTickHook()** first to give your application a chance to do something as soon as the tick is serviced because you may have some time critical work to do. Most of the work done by **OSTimeTick()** basically consist of decrementing the **OSTCBDly** field for each **OS\_TCB** (if it's nonzero). **OSTimeTick()** follows the chain of **OS\_TCB** starting at **OSTCBList** L3.20(2) until it reaches the idle task L3.20(3). When the **OSTCBDly** field of a task's **OS\_TCB** is decremented to zero, the task is made ready to run L3.20(4). The task is not readied, however, if it was explicitly suspended by **OSTaskSuspend()** L3.20(5). The execution time of **OSTimeTick()** is directly proportional to the number of tasks created in an application.

```

void OSTimeTick (void)
{
    OS_TCB *ptcb;

    OSTimeTickHook();                                     (1)
    ptcb = OSTCBLList;                                   (2)
    while (ptcb->OSTCBPrio != OS_IDLE_PRIO) {             (3)
        OS_ENTER_CRITICAL();
        if (ptcb->OSTCBDly != 0) {
            if (--ptcb->OSTCBDly == 0) {
                if (!(ptcb->OSTCBStat & OS_STAT_SUSPEND)) { (5)
                    OSRdyGrp          |= ptcb->OSTCBBitY;   (4)
                    OSRdyTbl[ptcb->OSTCBY] |= ptcb->OSTCBBitX;
                } else {
                    ptcb->OSTCBDly = 1;
                }
            }
        }
        ptcb = ptcb->OSTCBNext;
        OS_EXIT_CRITICAL();
    }
    OS_ENTER_CRITICAL();                                 (7)
    OSTime++;                                           (6)
    OS_EXIT_CRITICAL();
}

```

### Listing 3.20, Code to service a tick.

**OSTimeTick()** also accumulates the number of clock ticks since power up in an unsigned 32-bit variable called **OSTime** L3.20(6). Note that I disable interrupts L3.20(7) before incrementing **OSTime** because on some processors, a 32-bit increment will most likely be done using multiple instructions.

If you don't like to make ISRs any longer than they must be, **OSTimeTick()** can be called at the task level as shown in listing 3.21. To do this, you would create a task which has a higher priority than all your application tasks. The tick ISR would need to signal this high priority task by using either a semaphore or a message mailbox.

```

void TickTask (void *pdata)
{
    pdata = pdata;
    for (;;) {
        OSMboxPend(...);    /* Wait for signal from Tick ISR */
        OSTimeTick();
    }
}

```

### Listing 3.21, Code to service a tick.

You would obviously need to create a mailbox (initialized to **NULL**) which would signal the task that a tick interrupt occurred. The tick ISR would now look as shown in listing 3.22.

```

void OSTickISR(void)
{
    Save processor registers;
}

```

```

    Call OSIntEnter() or increment OSIntNesting;

    Post a 'dummy' message (e.g. (void *)1) to the tick mailbox;

    Call OSIntExit();
    Restore processor registers;
    Execute a return from interrupt instruction;
}

```

**Listing 3.22, Code to service a tick.**

### **3.11 $\mu$ C/OS-II Initialization**

A requirement of  $\mu$  C/OS-II is that you call **OSInit()** before you call any of its other services. **OSInit()** initializes all of  $\mu$  C/OS-II's variables and data structures (see **OS\_CORE.C**).

**OSInit()** creates the idle task (**OSTaskIdle()**) which is always ready-to-run. The priority of **OSTaskIdle()** is always set to **OS\_LOWEST\_PRIO**. If **OS\_TASK\_STAT\_EN** and **OS\_TASK\_CREATE\_EXT\_EN** (see **OS\_CFG.H**) are both set to 1, **OSInit()** also creates the statistic task, **OSTaskStat()** and makes it ready-to-run. The priority of **OSTaskStat()** is always set to **OS\_LOWEST\_PRIO - 1**.

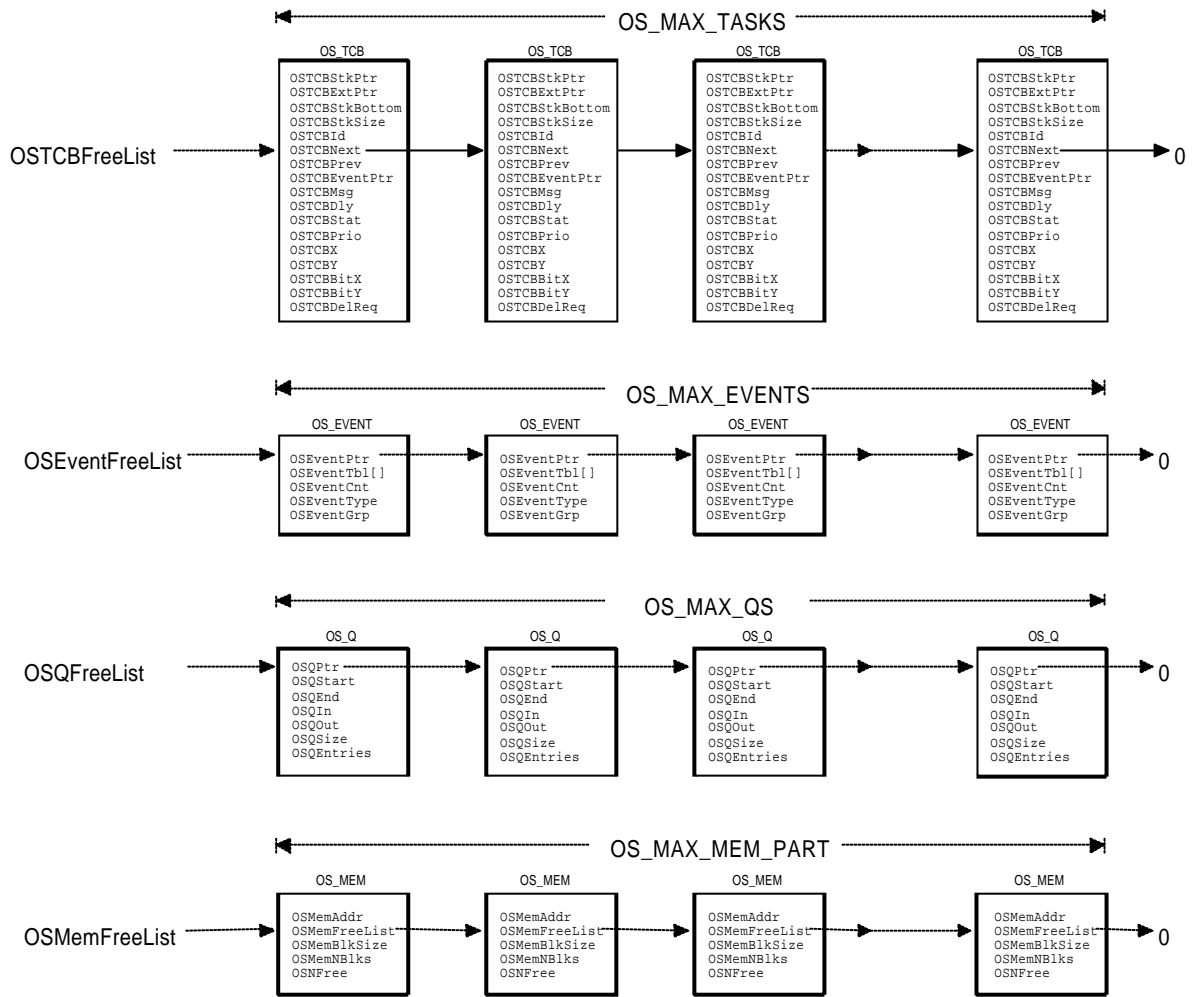
Figure 3-7 shows the relationship between some of  $\mu$  C/OS-II's variables and data structures after calling **OSInit()**. The illustration assumes that:

1. **OS\_TASK\_STAT\_EN** is set to 1 in **OS\_CFG.H**
2. **OS\_LOWEST\_PRIO** is set to 63 in **OS\_CFG.H**
3. **OS\_MAX\_TASKS** is set to a value higher than 2 in **OS\_CFG.H**

The Task Control Blocks (**OS\_TCBs**) of these two tasks are chained together in a doubly-linked list. **OSTCBList** points to the beginning of this chain. When a task is created, it is always placed at the beginning of the list. In other words, **OSTCBList** always points to the **OS\_TCB** of last task created. The ends of the chain point to **NULL** (i.e. 0).

Because both tasks are ready-to-run, their corresponding bit in **OSRdyTbl[]** are set to 1. Also, because the bit of both tasks are on the same row in **OSRdyTbl[]**, only one bit in **OSRdyGrp** is set to 1.





**Figure 3-8, Free Pools**

### 3.12 Starting $\mu$ C/OS-II

You start multitasking by calling **OSStart()**. Before you start  $\mu$  C/OS-II, however, you MUST create at least one of your application tasks as shown in listing 3.23.

```
void main (void)
{
    OSInit();           /* Initialize uC/OS-II                */
    .
    .
    Create at least 1 task using either OSTaskCreate() or OSTaskCreateExt();
    .
    .
    OSStart();          /* Start multitasking!  OSStart() will not return */
}
```

#### Listing 3.23, Initializing and Starting $\mu$ C/OS-II.

The code for **OSStart()** is shown in listing 3.24. When called, **OSStart()** finds the **OS\_TCB** of the highest priority task that you have created (done through the ready list) L3.24(1). Then, **OSStart()** calls **OSStartHighRdy()** L3.24(2) (see **OS\_CPU\_A.ASM**) for the processor being used. Basically, **OSStartHighRdy()** restores the CPU registers by popping them off the task's stack and then, executes a return from interrupt instruction which forces the CPU to execute your task's code (see Section 9.04.01, **OS\_CPU\_A.ASM**, **OSStartHighRdy()** for details on how this is done for the 80x86). You should note that **OSStartHighRdy()** will never return to **OSStart()**.

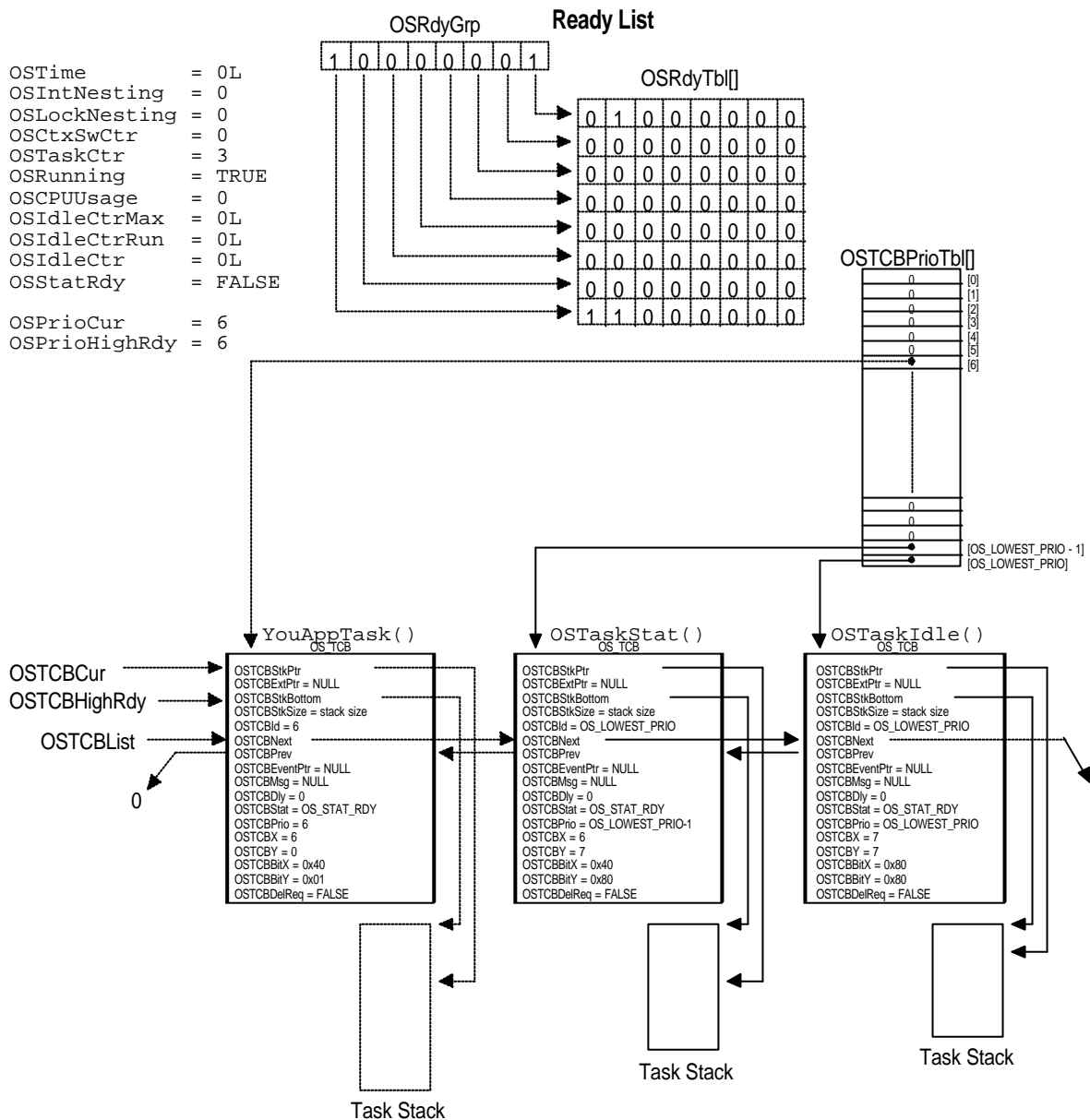
```
void OSStart (void)
{
    INT8U y;
    INT8U x;

    if (OSRunning == FALSE) {
        y          = OSUnMapTbl[OSRdyGrp];
        x          = OSUnMapTbl[OSRdyTbl[y]];
        OSPrioHighRdy = (INT8U)((y << 3) + x);
        OSPrioCur   = OSPrioHighRdy;
        OSTCBHighRdy = OSTCBPrioTbl[OSPrioHighRdy];           (1)
        OSTCBCur      = OSTCBHighRdy;                         (2)
        OSStartHighRdy();
    }
}
```

#### Listing 3.24, Starting multitasking.

Figure 3-9 shows the contents of the variables and data structures after multitasking has started. Here I assumed that the task you created has a priority of 6. You will notice that **OSTaskCtr** indicates that three tasks have been created, **OSRunning** is set to **TRUE** indicating that multitasking has started, **OSPrioCur** and **OSPrioHighRdy** contain the priority of your application task and, **OSTCBCur** and **OSTCBHighRdy** both point to the **OS\_TCB** of your task.





**Figure 3-9, Variables and Data Structures after calling OSStart()**

### 3.13 Obtaining $\mu$ C/OS-II's version

You can obtain the current version of  $\mu$ C/OS-II from your application by calling `OSVersion()`. `OSVersion()` returns the version number multiplied by 100. In other words, version 1.00 would be returned as 100.

```

INT16U OSVersion (void)
{
    return (OS_VERSION);
}

```

**Listing 3.25, Getting  $\mu$ C/OS-II's version.**

To find out about the latest version of  $\mu$  C/OS-II and how to obtain an upgrade, you should either contact the publisher or check the official  $\mu$  C/OS-II WEB site at [www.uCOS-II.com](http://www.uCOS-II.com).

### ***3.14 OSEvent???( ) functions***

You probably noticed that **OS\_CORE.C** has four functions that were not mentioned in this chapter. These functions are **OSEventWaitListInit()**, **OSEventTaskRdy()**, **OSEventTaskWait()** and **OSEventTO()**. I placed these functions in **OS\_CORE.C** but I will explain their use in Chapter 6, *Intertask Communication & Synchronization*.

## Chapter 4

# Task Management

We saw in the previous chapter that a task is either an infinite loop function or a function that deletes itself when it is done executing. Note that the task code is not actually deleted,  $\mu$ C/OS-II simply doesn't know about the task anymore and thus that code will not run. A task look just like any other C function containing a return type and an argument but, it must never return. The return type of a task must always be declared to be **void**. The functions described in this chapter are found in the file **OS\_TASK.C**. To review, a task must look as shown below.

```
void YourTask (void *pdata)
{
    for (;;) {
        /* USER CODE */
        Call one of uC/OS-II's services:
        OSMboxPend();
        OSQPend();
        OSSemPend();
        OSTaskDel(OS_PRIO_SELF);
        OSTaskSuspend(OS_PRIO_SELF);
        OSTimeDly();
        OSTimeDlyHMSM();
        /* USER CODE */
    }
}
```

or,

```

void YourTask (void *pdata)
{
    /* USER CODE */
    OSTaskDel(OS_PRIO_SELF);
}

```

This chapter describes the services that allow your application to create a task, delete a task, change a task's priority, suspend and resume a task and, allow your application to obtain information about a task.

μ C/OS-II can manage up to 64 tasks although μ C/OS-II reserves the four highest priority tasks and the four lowest priority tasks for its own use. This leaves you with up to 56 application tasks. The lower the value of the priority, the higher the priority of the task. In the current version of μ C/OS-II, the task priority number also serves as the task identifier.

## 4.00 Creating a Task, *OSTaskCreate()*

In order for μ C/OS-II to manage your task, you must 'create' a task. You create a task by passing its address along with other arguments to one of two functions: **OSTaskCreate()** or **OSTaskCreateExt()**. **OSTaskCreate()** is backward compatible with μ C/OS while **OSTaskCreateExt()** is an 'extended' version of **OSTaskCreate()** and provides additional features. A task can either be created using either function. A task can be created prior to the start of multitasking or by another task. You **MUST** create at least one task before you start multitasking (i.e. before you call **OSStart()**). A task cannot be created by an ISR.

The code for **OSTaskCreate()** is shown in listing 4.1. As can be seen, **OSTaskCreate()** requires four arguments. **task** is a pointer to the task code, **pdata** is a pointer to an argument that will be passed to your task when it starts executing, **ptos** is a pointer to the top of the stack that will be assigned to the task (see section 4.02, *Task Stacks*) and finally, **prio** is the desired task priority.

```

INT8U OSTaskCreate (void (*task)(void *pd), void *pdata, OS_STK *ptos, INT8U prio)
{
    void *psp;
    INT8U err;

    if (prio > OS_LOWEST_PRIO) {
        return (OS_PRIO_INVALID);
    }
    OS_ENTER_CRITICAL();
    if (OSTCBPrioTbl[prio] == (OS_TCB *)0) {
        OSTCBPrioTbl[prio] = (OS_TCB *)1;
        OS_EXIT_CRITICAL();
        psp = (void *)OSTaskStkInit(task, pdata, ptos, 0);
        err = OSTCBInit(prio, psp, (void *)0, 0, 0, (void *)0, 0);
        if (err == OS_NO_ERR) {
            OS_ENTER_CRITICAL();
            OSTaskCtr++;
            OSTaskCreateHook(OSTCBPrioTbl[prio]);
            OS_EXIT_CRITICAL();
            if (OSRunning) {
                OSSched();
            }
        } else {
            OSTCBPrioTbl[prio] = (OS_TCB *)0;
        }
        return (err);
    } else {
        OS_EXIT_CRITICAL();

```

```

    }
    return (OS_PRIO_EXIST);
}

```

## Listing 4.1, OSTaskCreate()

**OSTaskCreate()** starts by checking that the task priority is valid L4.1(1). The priority of a task must be a number between 0 and **OS\_LOWEST\_PRIO**, inclusively. Next, **OSTaskCreate()** makes sure that a task has not already been created at the desired priority L4.1(2). With  $\mu$  C/OS-II, all tasks must have a unique priority. If the desired priority is free then  $\mu$  C/OS-II ‘reserves’ the priority by placing a non-NULL pointer in **OSTCBPrioTbl[]** L4.1(3). This allows **OSTaskCreate()** to re-enable interrupts L4.1(4) while it sets up the rest of the data structures for the task.

**OSTaskCreate()** then calls **OSTaskStkInit()** L4.1(5) which is responsible for setting up the task stack. This function is processor specific and is found in **OS\_CPU\_C.C**. Refer to Chapter 8, *Porting  $\mu$  C/OS-II* for details on how to implement **OSTaskStkInit()**. If you already have a port of  $\mu$  C/OS-II for the processor you are intending to use then, you don’t need to be concerned about implementation details. **OSTaskStkInit()** returns the new top-of-stack (**psp**) which will be saved in the task’s **OS\_TCB**. You should note that the fourth argument (i.e. **opt**) to **OSTaskStkInit()** is set to 0. This is because, unlike **OSTaskCreateExt()**, **OSTaskCreate()** does not support options and thus, there are no options to pass to **OSTaskStkInit()**.

$\mu$  C/OS-II supports processors that have stacks that grow from either high memory to low memory or from low memory to high memory. When you call **OSTaskCreate()**, you must know how the stack grows (see **OS\_CPU.H** (**OS\_STACK\_GROWTH**) of the processor you are using) because you must pass the task’s top-of-stack to **OSTaskCreate()** which can either be the lowest memory location of the stack or the highest memory location of the stack.

Once **OSTaskStkInit()** has completed setting up the stack, **OSTaskCreate()** calls **OSTCBInit()** L4.1(6) to obtain and initialize an **OS\_TCB** from the pool of free **OS\_TCBs**. The code for **OSTCBInit()** is shown in listing 4.2 but is found in **OS\_CORE.C** instead of **OS\_TASK.C**. **OSTCBInit()** first tries to obtain an **OS\_TCB** from the **OS\_TCB** pool L4.2(1). If the pool contained a free **OS\_TCB** L4.2(2) then the **OS\_TCB** is initialized L4.2(3). Note that once an **OS\_TCB** is allocated, we can re-enable interrupts because, at this point, the creator of the task ‘owns’ the **OS\_TCB** and it cannot be corrupted by another concurrent task creation. We can thus proceed to initialize some of the **OS\_TCB** fields with interrupts enabled.

```

INT8U OSTCBInit (INT8U prio,      OS_STK *ptos, OS_STK *pbos, INT16U id,
                INT16U stk_size, void *pext,  INT16U opt)
{
    OS_TCB *ptcb;

    OS_ENTER_CRITICAL();
    ptcb = OSTCBFreeList;                                (1)
    if (ptcb != (OS_TCB *)0) {                             (2)
        OSTCBFreeList = ptcb->OSTCBNext;
        OS_EXIT_CRITICAL();
        ptcb->OSTCBStkPtr = ptos;                          (3)
        ptcb->OSTCBPrio = (INT8U)prio;
        ptcb->OSTCBStat = OS_STAT_RDY;
        ptcb->OSTCBDly = 0;
#ifdef OS_TASK_CREATE_EXT_EN
        ptcb->OSTCBExtPtr = pext;
        ptcb->OSTCBStkSize = stk_size;
        ptcb->OSTCBStkBottom = pbos;
        ptcb->OSTCBOpt = opt;
        ptcb->OSTCBId = id;
#else

```

```

        pext                = pext;
        stk_size            = stk_size;
        pbos                = pbos;
        opt                 = opt;
        id                  = id;
    #endif

    #if OS_TASK_DEL_EN
        ptcb->OSTCBDelReq    = OS_NO_ERR;
    #endif

        ptcb->OSTCBY         = prio >> 3;
        ptcb->OSTCBBitY      = OSMaTbl[ptcb->OSTCBY];
        ptcb->OSTCBX         = prio & 0x07;
        ptcb->OSTCBBitX      = OSMaTbl[ptcb->OSTCBX];

    #if OS_MBOX_EN || (OS_Q_EN && (OS_MAX_QS >= 2)) || OS_SEM_EN
        ptcb->OSTCBEventPtr  = (OS_EVENT *)0;
    #endif

    #if OS_MBOX_EN || (OS_Q_EN && (OS_MAX_QS >= 2))
        ptcb->OSTCBMsg       = (void *)0;
    #endif

        OS_ENTER_CRITICAL();
        OSTCBPrioTbl[prio]   = ptcb;
        ptcb->OSTCBNext      = OSTCBLst;
        ptcb->OSTCBPrev      = (OS_TCB *)0;
        if (OSTCBLst != (OS_TCB *)0) {
            OSTCBLst->OSTCBPrev = ptcb;
        }
        OSTCBLst             = ptcb;
        OSRdyGrp             |= ptcb->OSTCBBitY;
        OSRdyTbl[ptcb->OSTCBY] |= ptcb->OSTCBBitX;
        OS_EXIT_CRITICAL();
        return (OS_NO_ERR);
    } else {
        OS_EXIT_CRITICAL();
        return (OS_NO_MORE_TCB);
    }
}

```

## Listing 4.2, OSTCBInit()

We disable interrupts L4.2(4) when we need to insert the **OS\_TCB** into the doubly linked list of tasks that have been created L4.2(5). The list starts at **OSTCBLst** and the **OS\_TCB** of a new task is always inserted at the beginning of the list. Finally, the task is made ready to run L4.2(6) and **OSTCBInit()** returns to its caller (**OSTaskCreate()**) with a code indicating that an **OS\_TCB** has been allocated and initialized L4.2(7).

We can now continue the discussion of **OSTaskCreate()** (see listing 4.1) Upon return from **OSTCBInit()**, **OSTaskCreate()** checks the return code L4.1(7) and upon success, increments the counter of the number of tasks created, **OSTaskCtr** L4.1(8). If **OSTCBInit()** failed, the priority level is relinquished by setting the entry in **OSTCBPrioTbl[prio]** to 0 L4.1(12). **OSTaskCreate()** then calls **OSTaskCreateHook()** L4.1(9) which is a user specified function that allows you to extend the functionality of **OSTaskCreate()**. For example, you could initialize and store the contents of floating-point registers, MMU registers or anything else that can be associated with a task. You would, however, typically store this additional information in memory that would be allocated by your application. **OSTaskCreateHook()** can be declared either in **OS\_CPU\_C.C** (if **OS\_CPU\_HOOKS\_EN** is set to 1) or elsewhere. Note that interrupts are disabled when **OSTaskCreate()** calls **OSTaskCreateHook()**. Because of this, you should keep the code in this function to a minimum because it can directly impact interrupt

latency. When called, **OSTaskCreateHook()** receives a pointer to the **OS\_TCB** of the task being created. This means that the hook function can access all members of the **OS\_TCB** data structure.

Finally, if **OSTaskCreate()** was called from a task (i.e. **OSRunning** is set to **TRUE** L4.1(10)) then the scheduler is called L4.1(11) to determine whether the created task has a higher priority than its creator. Creating a higher priority task will result in a context switch to the new task. If the task was created before multitasking has started (i.e. you did not call **OSStart()** yet) then the scheduler is not called.

## 4.01 Creating a Task, **OSTaskCreateExt()**

Creating a task using **OSTaskCreateExt()** offers you more flexibility but, at the expense of additional overhead. The code for **OSTaskCreateExt()** is shown in listing 4.3.

As can be seen, **OSTaskCreateExt()** requires nine (9) arguments! The first four arguments (**task**, **pdata**, **ptos** and **prio**) are exactly the same as with **OSTaskCreate()** and also, they are located in the same order. I did that to make it easier to migrate your code to use **OSTaskCreateExt()**.

The **id** establishes a unique identifier for the task being created. This argument has been added for future expansion and is otherwise unused by  $\mu$  C/OS-II. This identifier will allow me to extend  $\mu$  C/OS-II beyond its limit of 64 tasks. For now, simply set the task's ID to the same value as the task's priority.

**pbos** is a pointer to the task's bottom-of-stack and this argument is used to perform stack checking.

**stk\_size** specifies the size of the stack in number of elements. This means that if a stack entry is 4 bytes wide then, a **stk\_size** of 1000 means that the stack will have 4000 bytes. Again, this argument is used for stack checking.

**pext** is a pointer to a user supplied data area that can be used to extend the **OS\_TCB** of the task. For example, you can add a name to a task (see Example #3), storage for the contents of floating-point registers during a context switch, port address to trigger an oscilloscope during a context switch and more.

Finally, **opt** specifies options to **OSTaskCreateExt()** to specify whether stack checking is allowed, whether the stack will be cleared, whether floating-point operations are performed by the task, etc. **uCOS\_II.H** contains a list of available options (**OS\_TASK\_OPT\_STK\_CHK**, **OS\_TASK\_OPT\_STK\_CLR**, and **OS\_TASK\_OPT\_SAVE\_FP**). Each option consists of a bit. The option is selected when the bit is set (you would simply OR the above **OS\_TASK\_OPT\_???** constants).

```
INT8U OSTaskCreateExt (void      (*task)(void *pd),
                      void      *pdata,
                      OS_STK     *ptos,
                      INT8U      prio,
                      INT16U     id,
                      OS_STK     *pbos,
                      INT32U      stk_size,
                      void      *pext,
                      INT16U     opt)
{
    void      *psp;
    INT8U      err;
    INT16U     i;
    OS_STK     *pfill;

    if (prio > OS_LOWEST_PRIO) {
        return (OS_PRIO_INVALID);
    }
    OS_ENTER_CRITICAL();
    (1)
```

```

if (OSTCBPrioTbl[prio] == (OS_TCB *)0) {           (2)
    OSTCBPrioTbl[prio] = (OS_TCB *)1;             (3)
    OS_EXIT_CRITICAL();                             (4)

    if (opt & OS_TASK_OPT_STK_CHK) {               (5)
        if (opt & OS_TASK_OPT_STK_CLR) {
            pfill = ppos;
            for (i = 0; i < stk_size; i++) {
                #if OS_STK_GROWTH == 1
                    *pfill++ = (OS_STK)0;
                #else
                    *pfill-- = (OS_STK)0;
                #endif
            }
        }
    }

    psp = (void *)OSTaskStkInit(task, pdata, ppos, opt); (6)
    err = OSTCBInit(prio, psp, ppos, id, stk_size, pext, opt); (7)
    if (err == OS_NO_ERR) {                         (8)
        OS_ENTER_CRITICAL;
        OSTaskCtr++;                               (9)
        OSTaskCreateHook(OSTCBPrioTbl[prio]);      (10)
        OS_EXIT_CRITICAL();
        if (OSRunning) {                           (11)
            OSSched();                             (12)
        }
    } else {
        OSTCBPrioTbl[prio] = (OS_TCB *)0;          (13)
    }
    return (err);
} else {
    OS_EXIT_CRITICAL();
    return (OS_PRIO_EXIST);
}
}

```

### Listing 4.3, OSTaskCreateExt()

**OSTaskCreateExt()** starts by checking that the task priority is valid L4.3(1). The priority of a task must be a number between 0 and **OS\_LOWEST\_PRIO**, inclusively. Next, **OSTaskCreateExt()** makes sure that a task has not already been created at the desired priority L4.3(2). With  $\mu$  C/OS-II, all tasks must have a unique priority. If the desired priority is free then  $\mu$  C/OS-II ‘reserves’ the priority by placing a non-NULL pointer in **OSTCBPrioTbl[]** L4.3(3). This allows **OSTaskCreateExt()** to re-enable interrupts L4.3(4) while it sets up the rest of the data structures for the task.

In order to perform stack checking (see section 4.03, *Stack Checking*) on a task, you must set the **OS\_TASK\_OPT\_STK\_CHK** flag in the **opt** argument. Also, stack checking requires that the stack contain zeros (i.e. it needs to be cleared) when the task is created. To specify that a task gets cleared when it is created, you would also set **OS\_TASK\_OPT\_STK\_CLR** in the **opt** argument. When both of these flags are set, **OSTaskCreateExt()** clears the stack L4.3(5).

**OSTaskCreateExt()** then calls **OSTaskStkInit()** L4.3(6) which is responsible for setting up the task stack. This function is processor specific and is found in **OS\_CPU\_C.C**. Refer to Chapter 8, *Porting  $\mu$  C/OS-II* for details on how to implement **OSTaskStkInit()**. If you already have a port of  $\mu$  C/OS-II for the processor you are intending to use then, you don’t need to be concerned about implementation details. **OSTaskStkInit()** returns the new top-of-stack (**psp**) which will be saved in the task’s **OS\_TCB**.



μC/OS-II supports processors that have stacks that grow from either high memory to low memory or from low memory to high memory (see section 4.02, *Task Stacks*). When you call **OSTaskCreateExt()**, you must know how the stack grows (see **OS\_CPU.H** of the processor you are using) because you must pass the task's top-of-stack to **OSTaskCreateExt()** which can either be the lowest memory location of the stack (when **OS\_STK\_GROWTH** is 0) or the highest memory location of the stack (when **OS\_STK\_GROWTH** is 1).

Once **OSTaskStkInit()** has completed setting up the stack, **OSTaskCreateExt()** calls **OSTCBInit()** L4.3(7) to obtain and initialize an **OS\_TCB** from the pool of free **OS\_TCBs**. The code for **OSTCBInit()** is shown and described with **OSTaskCreate()** (see section 4.00). Upon return from **OSTCBInit()**, **OSTaskCreateExt()** checks the return code L4.3(8) and upon success, increments the counter of the number of tasks created, **OSTaskCtr** L4.3(9). If **OSTCBInit()** failed, the priority level is relinquished by setting the entry in **OSTCBPrioTbl[prio]** to 0 L4.3(13). **OSTaskCreateExt()** then calls **OSTaskCreateHook()** L4.3(10) which is a user specified function that allows you to extend the functionality of **OSTaskCreateExt()**. **OSTaskCreateHook()** can be declared either in **OS\_CPU.C** (if **OS\_CPU\_HOOKS\_EN** is set to 1) or elsewhere (if **OS\_CPU\_HOOKS\_EN** is set to 0). Note that interrupts are disabled when **OSTaskCreateExt()** calls **OSTaskCreateHook()**. Because of this, you should keep the code in this function to a minimum because it can directly impact interrupt latency. When called, **OSTaskCreateHook()** receives a pointer to the **OS\_TCB** of the task being created. This means that the hook function can access all members of the **OS\_TCB** data structure.

Finally, if **OSTaskCreateExt()** was called from a task (i.e. **OSRunning** is set to **TRUE** L4.3(11)) then the scheduler is called L4.3(12) to determine whether the created task has a higher priority than its creator. Creating a higher priority task will result in a context switch to the new task. If the task was created before multitasking has started (i.e. you did not call **OSStart()** yet) then the scheduler is not called.

## 4.02 Task Stacks

Each task MUST have its own stack space. A stack MUST be declared as being of type **OS\_STK** and MUST consist of contiguous memory locations. You can either allocate stack space 'statically' (i.e. compile-time) or 'dynamically' (run-time). A static stack declaration looks as shown below. Both of these declarations are made outside a function.

```
static OS_STK  MyTaskStack[stack_size];
```

### Listing 4.4, Static Stack

or,

```
OS_STK  MyTaskStack[stack_size];
```

### Listing 4.5, Static Stack

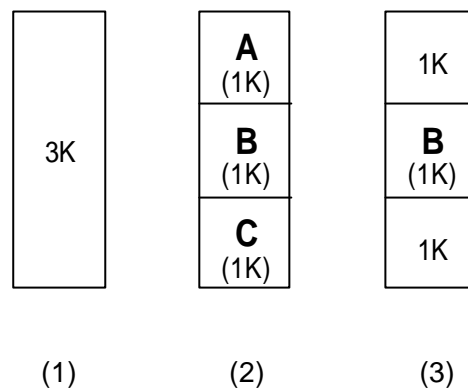
You can allocate stack space dynamically by using the C compiler's **malloc()** function as shown in listing 4.6. However, you must be careful with fragmentation. Specifically, if you create and delete tasks then, eventually, your memory allocator may not be able to return a stack for your task(s) because the heap gets fragmented.

```
OS_STK  *pstk;

pstk = (OS_STK *)malloc(stack_size);
if (pstk != (OS_STK *)0) {          /* Make sure malloc() had enough space */
    Create the task;
}
```

### Listing 4.6, Using ‘malloc()’ to allocate stack space for a task

Figure 4-1 illustrates a heap containing 3 Kbytes or available memory that can be allocated with `malloc()` F4-1(1). For sake of discussion, you create 3 tasks (task A, B and C) each requiring 1K. We will also assume that the first 1 Kbytes is given to task A, the second to task B and the third to C F4-1(2). Your application then deletes task A and task B and, relinquishes the memory back to the heap using `free()` F4-1(3). Your heap now has 2 Kbytes of memory free but, it's not contiguous. This means that you could not create another task (i.e. task D) that required 2 Kbytes. Your heap is thus fragmented. If, however, you never delete a task then using `malloc()` is perfectly acceptable.



**Figure 4-1, Fragmentation.**

μC/OS-II supports processors that have stacks that grow from either high memory to low memory or from low memory to high memory. When you call either `OSTaskCreate()` or `OSTaskCreateExt()`, you must know how the stack grows because you need to pass the task's top-of-stack to the task creation function. When `OS_STK_GROWTH` is set to 0 in `OS_CPU.H`, you need to pass the lowest memory location of the stack to the task create function as shown in listing 4.7.

```
OS_STK TaskStack[TASK_STACK_SIZE];

OSTaskCreate(task, pdata, &TaskStack[0], prio);
```

### Listing 4.7, Stack grows from LOW memory to HIGH memory

When `OS_STK_GROWTH` is set to 1 in `OS_CPU.H`, you need to pass the highest memory location of the stack to the task create function as shown in listing 4.8.

```
OS_STK TaskStack[TASK_STACK_SIZE];

OSTaskCreate(task, pdata, &TaskStack[TASK_STACK_SIZE-1], prio);
```

### Listing 4.8, Stack grows from HIGH memory to LOW memory

This requirement affects code portability. If you need to port your code from a processor architecture that supports a downward growing stack to an upward growing stack then you may need to do like I did in `OS_CORE.C` for `OSTaskIdle()` and `OSTaskStat()`. Specifically, with the above example, your code would look as shown in listing 4.9.

```
OS_STK TaskStack[TASK_STACK_SIZE];

#if OS_STK_GROWTH == 0
    OSTaskCreate(task, pdata, &TaskStack[0], prio);
#else
    OSTaskCreate(task, pdata, &TaskStack[TASK_STACK_SIZE-1], prio);
#endif
```

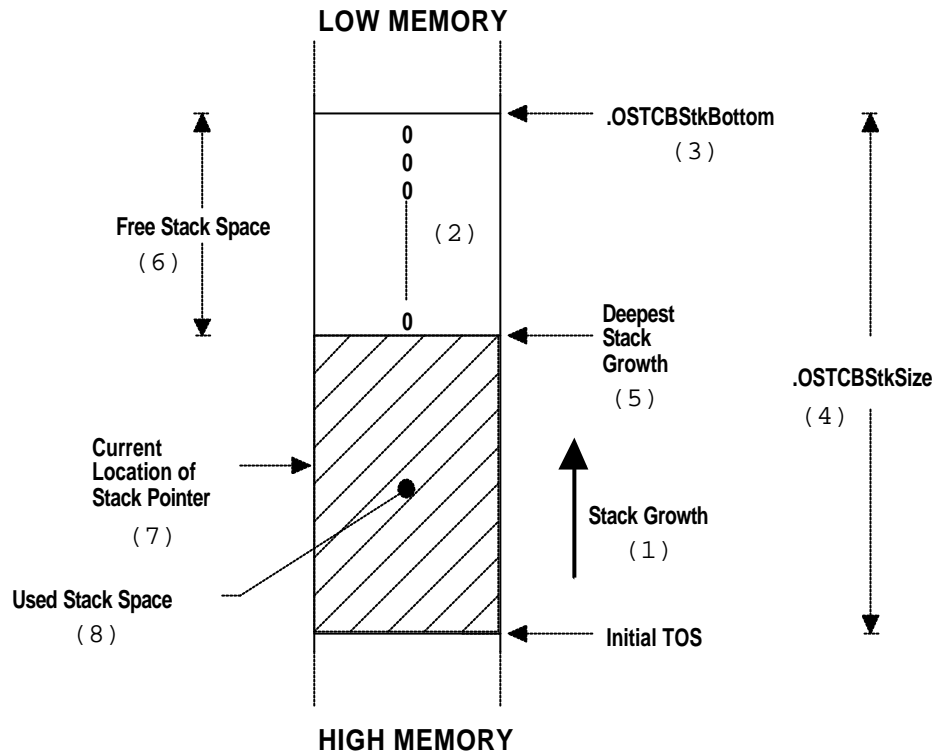
### Listing 4.9, Supporting stacks which grow in either direction.

The size of the stack needed by your task is application specific. When sizing the stack, however, you must account for nesting of all the functions called by your task, the number of local variables that will be allocated by all functions called by your task and, the stack requirements for all nested interrupt service routines. In addition, your stack must be able to store all CPU registers.

## 4.03 Stack Checking, *OSTaskStkChk()*

It is sometimes necessary to determine how much stack space a task actually uses. This allows you to reduce the amount of RAM needed by your application code by not over allocating stack space.  $\mu$ C/OS-II provides a function called `OSTaskStkChk()` that provides you with this valuable information.

Refer to figure 4-2 for the following discussion. Stack checking is performed on demand as opposed to continuously. Note that figure 4-2 assumes that stack grows from high memory to low memory (i.e. `OS_STK_GROWTH` is set to 1) but, the discussion applies equally well to a stack growing in the opposite direction F4-2(1).  $\mu$ C/OS-II determines stack growth by looking at the contents of the stack itself. To perform stack checking,  $\mu$ C/OS-II requires that the stack get filled with zeros when the task is created F4-2(2). Also,  $\mu$ C/OS-II needs to know the location of the bottom-of-stack (BOS) F4-2(3) and the size of the stack you assigned to the task F4-2(4). These two values are stored in the task's `OS_TCB` when the task is created.



**Figure 4-2, Stack checking**

In order for you to use  $\mu$ C/OS-II's stack checking facilities, you MUST do the following:

1. Set `OS_TASK_CREATE_EXT` to 1 in `OS_CFG.H`.
2. Create a task using `OSTaskCreateExt()` and give the task much more space than you think it really needs.
3. Set the `opt` argument in `OSTaskCreateExt()` to `OS_TASK_OPT_STK_CHK + OS_TASK_OPT_STK_CLR`. Note that if your startup code clears all RAM and you never delete tasks once they are created then, you don't need to set the `OS_TASK_OPT_STK_CLR` option. This will reduce the execution time of `OSTaskCreateExt()`.
4. Call `OSTaskStkChk()` by specifying the priority of the task you desire to check.

`OSTaskStkChk()` computes the amount of free stack space by 'walking' from the bottom of the stack and counting the number of zero entries on the stack until a non-zero value is found F4-2(5). Note that stack entries are checked using the data type of the stack (see `OS_STK` in `OS_CPU.H`). In other words, if a stack entry is 32-bit wide then the comparison for a zero value is done using 32 bits. The amount of stack space used F4-2(8) is obtained by subtracting the number of zero value entries F4-2(6) from the stack size you specified in `OSTaskCreateExt()`. `OSTaskStkChk()` actually places the number of bytes free and the number of bytes used in a data structure of type `OS_STK_DATA` (see `uCOS_II.H`). You should note that at any given time, the stack pointer for the task being checked may be pointing somewhere between the initial Top-Of-Stack (TOS) and the deepest stack growth F4-2(7). Also, every time you call `OSTaskStkChk()`, you may get a different value for the amount of free space on the stack until your task has reached its deepest growth F4-2(5).

You will need to run the application long enough and under your worst case conditions to get proper numbers. Once `OSTaskStkChk()` provides you with the worst case stack requirement, you can go back and set the final size of your

stack. You should accommodate for system expansion so make sure you allocate between 10 and 25% more. What you should get from stack checking is a 'ballpark' figure; you are not looking for an exact stack usage.

The code for **OSTaskStkChk()** is shown in listing 4.10. The data structure **OS\_STK\_DATA** (see uCOS\_II.H) is used to hold information about the task stack. I decided to use a data structure for two reasons. First, I consider **OSTaskStkChk()** to be a 'query' type function and I wanted to have all query functions work the same way— return data about the query in a data structure. Second, passing data in a data structure is both efficient and allows me to add additional fields in the future without changing the API (Application Programming Interface) of **OSTaskStkChk()**. For now, **OS\_STK\_DATA** only contains two fields: **OSFree** and **OSUsed**. As you can see, you invoke **OSTaskStkChk()** by specifying the priority of the task you desire to perform stack checking on. If you specify **OS\_PRIO\_SELF** L4.10(1) then it is assumed that you desire to know the stack information about the current task. Obviously, the task must exist L4.10(2). To perform stack checking, you must have created the task using **OSTaskCreateExt()** and you must have passed the option **OS\_TASK\_OPT\_STK\_CHK** L4.10(3). If all the proper conditions are met, **OSTaskStkChk()** computes the free stack space as described above by 'walking' from the bottom of stack until a non-zero stack entry is encountered L4.10(4). Finally, the information to store in **OS\_STK\_DATA** is computed L4.10(5). Note that the function computes the actual number of bytes free and the number of bytes used on the stack as opposed to the number of elements. Obviously, the actual stack size (in bytes) can be obtained by adding these two values.

```

INT8U OSTaskStkChk (INT8U prio, OS_STK_DATA *pdata)
{
    OS_TCB  *ptcb;
    OS_STK   *pchk;
    INT32U   free;
    INT32U   size;

    pdata->OSFree = 0;
    pdata->OSUsed = 0;
    if (prio > OS_LOWEST_PRIO && prio != OS_PRIO_SELF) {
        return (OS_PRIO_INVALID);
    }
    OS_ENTER_CRITICAL();
    if (prio == OS_PRIO_SELF) {           (1)
        prio = OSTCBCur->OSTCBPrio;
    }
    ptcb = OSTCBPrioTbl[prio];
    if (ptcb == (OS_TCB *)0) {           (2)
        OS_EXIT_CRITICAL();
        return (OS_TASK_NOT_EXIST);
    }
    if ((ptcb->OSTCBOpt & OS_TASK_OPT_STK_CHK) == 0) {           (3)
        OS_EXIT_CRITICAL();
        return (OS_TASK_OPT_ERR);
    }
    free = 0;                           (4)
    size = ptcb->OSTCBStkSize;
    pchk = ptcb->OSTCBStkBottom;
    OS_EXIT_CRITICAL();
    #if OS_STK_GROWTH == 1
        while (*pchk++ == 0) {
            free++;
        }
    #else
        while (*pchk-- == 0) {
            free++;
        }
    #endif
    pdata->OSFree = free * sizeof(OS_STK);           (5)
    pdata->OSUsed = (size - free) * sizeof(OS_STK);
    return (OS_NO_ERR);
}

```

**Listing 4.10, Stack checking function**

#### ***4.04 Deleting a Task, OSTaskDel()***

It is sometimes necessary to delete a task. Deleting a task means that the task will be returned to the DORMANT state (see Section 3.02, *Task States*) and does not mean that the code for the task will be deleted. The task code is simply no longer scheduled by  $\mu$  C/OS-II. You delete a task by calling **OSTaskDel()** and the code for this function is shown in listing 4.11. Here, we start by making sure that you are not attempting to delete the idle task because this is not allowed L4.11(1). You are, however, allowed to delete the statistic task L4.11(2). **OSTaskDel()** then checks to make sure you are not attempting to delete a task from within an ISR which is again not allowed L4.11(3). The caller can delete itself by specifying **OS\_PRIO\_SELF** as the argument L4.11(4). We then verify that the task to delete does in fact exist L4.11(5). This test will obviously pass if you specified **OS\_PRIO\_SELF**. I didn't want to create a separate case for this situation because it would have increased code size and thus execution time.

Once all conditions are satisfied, the **OS\_TCB** is removed from all the possible  $\mu$ C/OS-II data structures. **OSTaskDel()** does this in two parts to reduce interrupt latency. First, if the task is in the ready list, it is removed L4.11(6). We then check to see if the task is in a list waiting for a mailbox, a queue or a semaphore and if so, the task is removed from that list L4.11(7). Next, we force the delay count to zero to make sure that the tick ISR will not ready this task once we re-enable interrupts L4.11(8). Finally, we set the task's **.OSTCBstat** flag to **OS\_STAT\_RDY**. Note that we are not trying to make the task ready, we are simply preventing another task or an ISR from resuming this task (i.e. in case the other task or ISR called **OSTaskResume()** L4.11(9)). This situation could occur because we will be re-enabling interrupts L4.11(11) so, an ISR can make a higher priority task ready which could resume the task we are trying to delete. Instead of setting the task's **.OSTCBstat** flag to **OS\_STAT\_RDY**, I could have simply cleared the **OS\_STAT\_SUSPEND** bit (which would have been clearer) but, this takes slightly more processing time.

At this point, the task to delete cannot be made ready to run by another task or an ISR because, it's been removed from the ready list, it's not waiting for an event to occur, it's not waiting for time to expire and cannot be resumed. In other words the task is DORMANT for all intents and purposes. Because of this, I must prevent the scheduler L4.11(10) from switching to another task because, if the current task is almost deleted then it would not be able to be rescheduled! At this point, we want to re-enable interrupts in order to reduce interrupt latency L4.11(11). We could thus service an interrupt but because we incremented **OSLockNesting** the ISR would return to the interrupted task. You should note that we are still not done with the deletion process because we need to unlink the **OS\_TCB** from the TCB chain and return the **OS\_TCB** to the free **OS\_TCB** list.

Note also that I call a 'dummy' function **OSDummy()** immediately after calling **OS\_EXIT\_CRITICAL()** L4.11(12). I do this because I want to make sure that the processor will execute at least one instruction with interrupts enabled. On many processors, executing an interrupt enable instruction forces the CPU to have interrupts *disabled* until the end of the next instruction! The Intel 80x86 and Zilog Z-80 processors actually work like this. Enabling and immediately disabling interrupts would behave just as if I didn't enable interrupts. This would of course increase interrupt latency. Calling **OSDummy()** thus ensures that I will execute a call and a return instruction before re-disabling interrupts. You could certainly replace **OSDummy()** with a macro that executes a 'no-operation' instruction and thus slightly reduce the execution time of **OSTaskDel()**. I didn't think it was worth the effort of creating yet another macro that would require porting.

We can now continue with the deletion process of the task. After we re-disable interrupts, re-enable scheduling by decrementing the lock nesting counter L4.11(13). We then call the user definable task delete hook, **OSTaskDelHook()** L4.11(14). This allows user defined TCB extensions to be relinquished. Next, we decrement the task counter to indicate that there is one less task being managed by  $\mu$ C/OS-II. We remove the **OS\_TCB** from the priority table by simply replacing the link to the **OS\_TCB** of the task being deleted with a **NULL** pointer L4.11(15). We then remove the **OS\_TCB** of the task to delete from the doubly-linked list of **OS\_TCBs** that starts at **OSTCBList** L4.11(16). You should note that there is no need to check for the case where **ptcb->OSTCBNext == 0** because we cannot delete the idle task which happens to always be at the end of the chain. The **OS\_TCB** is returned to the free list of **OS\_TCBs** to allow another task to be created L4.11(17). Last, but not least, the scheduler L4.11(18) is called to see if a higher priority task has been made ready to run by an ISR that would have occurred when we re-enabled interrupts at step L4.11(11).

```

INT8U OSTaskDel (INT8U prio)
{
    OS_TCB  *ptcb;
    OS_EVENT *pevent;

    if (prio == OS_IDLE_PRIO) {                                (1)
        return (OS_TASK_DEL_IDLE);
    }
    if (prio >= OS_LOWEST_PRIO && prio != OS_PRIO_SELF) {      (2)
        return (OS_PRIO_INVALID);
    }
    OS_ENTER_CRITICAL();
    if (OSIntNesting > 0) {                                    (3)

```

```

        OS_EXIT_CRITICAL();
        return (OS_TASK_DEL_ISR);
    }
    if (prio == OS_PRIO_SELF) {                                (4)
        prio = OSTCBCur->OSTCBPrio;
    }
    if ((ptcb = OSTCBPrioTbl[prio]) != (OS_TCB *)0) {          (5)
        if ((OSRdyTbl[ptcb->OSTCBY] &= ~ptcb->OSTCBBitX) == 0) { (6)
            OSRdyGrp &= ~ptcb->OSTCBBitY;
        }
        if ((pevent = ptcb->OSTCBEventPtr) != (OS_EVENT *)0) { (7)
            if ((pevent->OSEventTbl[ptcb->OSTCBY] &= ~ptcb->OSTCBBitX) == 0) {
                pevent->OSEventGrp &= ~ptcb->OSTCBBitY;
            }
        }
        ptcb->OSTCBDly = 0;                                     (8)
        ptcb->OSTCBStat = OS_STAT_RDY;                         (9)
        OSLockNesting++;                                       (10)
        OS_EXIT_CRITICAL();                                    (11)
        OSDummy();                                              (12)
        OS_ENTER_CRITICAL();
        OSLockNesting--;                                       (13)
        OStaskDelHook(ptcb);                                   (14)
        OSTaskCtr--;
        OSTCBPrioTbl[prio] = (OS_TCB *)0;                     (15)
        if (ptcb->OSTCBPrev == (OS_TCB *)0) {                  (16)
            ptcb->OSTCBNext->OSTCBPrev = (OS_TCB *)0;
            OSTCBList = ptcb->OSTCBNext;
        } else {
            ptcb->OSTCBPrev->OSTCBNext = ptcb->OSTCBNext;
            ptcb->OSTCBNext->OSTCBPrev = ptcb->OSTCBPrev;
        }
        ptcb->OSTCBNext = OSTCBFreeList;                       (17)
        OSTCBFreeList = ptcb;
        OS_EXIT_CRITICAL();
        OSSched();                                              (18)
        return (OS_NO_ERR);
    } else {
        OS_EXIT_CRITICAL();
        return (OS_TASK_DEL_ERR);
    }
}

```

**Listing 4.11, Task Delete**

### ***4.05 Requesting to delete a task, OSTaskDelReq()***

Sometimes, a task may own resources such as a memory buffers or a semaphore. If another task attempts to delete this task then, the resource would not be freed and thus would be lost. In this type of situation, you would need to somehow signal the task that owns these resources to tell it to delete itself when it's done with the resources. You can accomplish this with the **OSTaskDelReq()** function.

Both the requestor and the task to be deleted need to call **OSTaskDelReq()**. The requestor code would look as shown in listing 4.12. The task that makes the request needs to determine what condition(s) will cause a request for the task to be deleted L4.12(1). In other words, your application will determine what condition(s) will lead to this decision. If the task needs to be deleted then you call **OSTaskDelReq()** by passing the priority of the task to be deleted L4.12(2). If the task to delete does not exist then **OSTaskDelReq()** returns **OS\_TASK\_NOT\_EXIST**. You would get this if the task to delete has already been deleted or, it has not been created yet. If the return value is **OS\_NO\_ERR** then, the request has been accepted but the task has not been deleted yet. You may want to wait until the task to be



deleted does in fact delete itself. You can do this by delaying the requestor for a certain amount of time like I did in L4.12(3). I decided to delay for one tick but you can certainly wait longer if needed. When the requested task eventually deletes itself, the return value in L4.12(2) would be **OS\_TASK\_NOT\_EXIST** and the loop would exit L4.12(4).

```
void RequestorTask (void *pdata)
{
    INT8U err;

    pdata = pdata;
    for (;;) {
        /* Application code */
        if ('TaskToBeDeleted()' needs to be deleted) {           (1)
            while (OSTaskDelReq(TASK_TO_DEL_PRIO) != OS_TASK_NOT_EXIST) { (2)
                OSTimeDly(1);                                     (3)
            }
        }
        /* Application code */                                   (4)
    }
}
```

### Listing 4.12, Requesting a task to delete itself.

The code for the task that needs to delete itself is shown in listing 4.13. This task basically needs to ‘poll’ a flag that resides inside the task’s **OS\_TCB**. The value of this flag is obtained by calling **OSTaskDelReq(OS\_PRIO\_SELF)**. When **OSTaskDelReq()** returns **OS\_TASK\_DEL\_REQ** L4.13(1) to its caller, it indicates that another task has requested that this task needs to be deleted. In this case, the task to be deleted releases any resources owned L4.13(2) and calls **OSTaskDel(OS\_PRIO\_SELF)** to delete itself L4.13(3). As previously mentioned, the code for the task is not actually deleted. Instead,  $\mu$ C/OS-II will simply not schedule the task for execution. In other word, the task code will no longer run. You can, however, re-create the task by calling either **OSTaskCreate()** or **OSTaskCreateExt()**.

```
void TaskToBeDeleted (void *pdata)
{
    INT8U err;

    pdata = pdata;
    for (;;) {
        /* Application code */
        if (OSTaskDelReq(OS_PRIO_SELF) == OS_TASK_DEL_REQ) {      (1)
            Release any owned resources;                          (2)
            De-allocate any dynamic memory;
            OSTaskDel(OS_PRIO_SELF);                               (3)
        } else {
            /* Application code */
        }
    }
}
```

### Listing 4.13, Requesting a task to delete itself.

The code for **OSTaskDelReq()** is shown in listing 4.14. As usual, we need to check for boundary conditions. First, we notify the caller in case he requests to delete the idle task L4.14(1). Next, we must ensure that the caller is not trying to request to delete an invalid priority L4.14(2). If the caller is the task to be deleted, the flag stored in the **OS\_TCB** will be returned L4.14(3). If you specified a task with a priority other than **OS\_PRIO\_SELF** then, if the task

exist L4.14(4), we set the internal flag for that task L4.14(5). If the task does not exist, we return **OS\_TASK\_NOT\_EXIST** to indicate that the task must have deleted itself L4.14(6).

```

INT8U OSTaskDelReq (INT8U prio)
{
    BOOLEAN  stat;
    INT8U     err;
    OS_TCB   *ptcb;

    if (prio == OS_IDLE_PRIO) {                      (1)
        return (OS_TASK_DEL_IDLE);
    }
    if (prio >= OS_LOWEST_PRIO && prio != OS_PRIO_SELF) { (2)
        return (OS_PRIO_INVALID);
    }
    if (prio == OS_PRIO_SELF) {                      (3)
        OS_ENTER_CRITICAL();
        stat = OSTCBCur->OSTCBDelReq;
        OS_EXIT_CRITICAL();
        return (stat);
    } else {
        OS_ENTER_CRITICAL();
        if ((ptcb = OSTCBPrioTbl[prio]) != (OS_TCB *)0) { (4)
            ptcb->OSTCBDelReq = OS_TASK_DEL_REQ;          (5)
            err                = OS_NO_ERR;
        } else {
            err                = OS_TASK_NOT_EXIST;      (6)
        }
        OS_EXIT_CRITICAL();
        return (err);
    }
}

```

**Listing 4.14, OSTaskDelReq().**

## 4.06 Changing a Task's Priority, OSTaskChangePrio()

When you create a task, you assign the task a priority. At run-time, you can change the priority of any task by calling **OSTaskChangePrio()**. In other words,  $\mu$ C/OS-II allows you to change priorities dynamically.

The code for **OSTaskChangePrio()** is shown in listing 4.15. You cannot change the priority of the idle task L4.15(1). You can either change the priority of the calling task or another task. To change the priority of the calling task you can must either specify the 'old' priority of that task or specify **OS\_PRIO\_SELF** and **OSTaskChangePrio()** will determine what the priority of the calling task is for you. You must also specify the 'new' (i.e. desired) priority. Because  $\mu$ C/OS-II cannot have multiple tasks running at the same priority, we need to check that the desired priority is available L4.15(2). If the desired priority is available,  $\mu$ C/OS-II reserves the priority by loading 'something' in the **OSTCBPrioTbl[]** thus reserving that entry L4.15(3). This allows us to re-enable interrupts and know that no other task can either create a task at the desired priority or have another task call **OSTaskChangePrio()** by specifying the same 'new' priority. This is done so that we can pre-compute some values that will be stored in the task's **OS\_TCB** L4.15(4). These values are used to put or remove the task in or from the ready list (see section 3.04, *Ready List*).

We then check to see if the current task is attempting to change its priority L4.15(5). Next, we need to see if the task for which we are trying to change the priority exist L4.15(6). Obviously, if it's the current task then this test will succeed. However, if we are trying to change the priority of a task that doesn't exist then, we must relinquish the 'reserved' priority back to the priority table, **OSTCBPrioTbl[]** L4.15(17), and return an error code to the caller.

We now remove the pointer to the **OS\_TCB** of the task from the priority table by inserting a **NULL** pointer L4.15(7). This will make the 'old' priority available for reuse. Then, we check to see if the task for which we are changing the priority is ready-to-run L4.15(8). If it is, it must be removed from the ready list at the current priority L4.15(9) and inserted back in the ready list at the new priority L4.15(10). Note here that we use our pre-computed values L4.15(4) to insert the task in the ready list.

If the task is ready then, it could be waiting on a semaphore, a mailbox or a queue. We know that the task is waiting for one of these events if the **OSTCBEventPtr** is non-**NULL** L4.15(11). If the task is waiting for an event, we must remove the task from the wait list (at the old priority) of the event control block (see section 6.00, *Event Control Block*) and insert the task back in the wait list but this time at the new priority L4.15(12). The task could be waiting for time to expire (see chapter 5, *Time Management*) or the task could be suspended (see section 4.07, *Suspending a Task*, *OSTaskSuspend()*). In these cases, items L4.15(8) through L4.15(12) would be skipped.

Next, we store a pointer to the task's **OS\_TCB** in the priority table, **OSTCBPrioTbl[ ]** L4.15(13). The new priority is saved in the **OS\_TCB** L4.15(14) and the pre-computed values are also saved in the **OS\_TCB** L4.15(15). After we exit the critical section, the scheduler is called in case the new priority is higher than the old priority or the priority of the calling task L4.15(16).

```

INT8U OSTaskChangePrio (INT8U oldprio, INT8U newprio)
{
    OS_TCB    *ptcb;
    OS_EVENT  *pevent;
    INT8U      x;
    INT8U      y;
    INT8U      bitx;
    INT8U      bity;

    if ((oldprio >= OS_LOWEST_PRIO && oldprio != OS_PRIO_SELF) || (1)
        newprio >= OS_LOWEST_PRIO) {
        return (OS_PRIO_INVALID);
    }
    OS_ENTER_CRITICAL();
    if (OSTCBPrioTbl[newprio] != (OS_TCB *)0) { (2)
        OS_EXIT_CRITICAL();
        return (OS_PRIO_EXIST);
    } else {
        OSTCBPrioTbl[newprio] = (OS_TCB *)1; (3)
        OS_EXIT_CRITICAL();
        y = newprio >> 3; (4)
        bity = OSMAPTbl[y];
        x = newprio & 0x07;
        bitx = OSMAPTbl[x];
        OS_ENTER_CRITICAL();
        if (oldprio == OS_PRIO_SELF) { (5)
            oldprio = OSTCBCur->OSTCBPrio;
        }
        if ((ptcb = OSTCBPrioTbl[oldprio]) != (OS_TCB *)0) { (6)
            OSTCBPrioTbl[oldprio] = (OS_TCB *)0; (7)
            if (OSRdyTbl[ptcb->OSTCBY] & ptcb->OSTCBBitX) { (8)
                if ((OSRdyTbl[ptcb->OSTCBY] & ~ptcb->OSTCBBitX) == 0) { (9)
                    OSRdyGrp &= ~ptcb->OSTCBBity;
                }
                OSRdyGrp |= bity; (10)
                OSRdyTbl[y] |= bitx;
            } else {
                if ((pevent = ptcb->OSTCBEventPtr) != (OS_EVENT *)0) { (11)
                    if ((pevent->OSEventTbl[ptcb->OSTCBY] & ~ptcb->OSTCBBitX) == 0) {
                        pevent->OSEventGrp &= ~ptcb->OSTCBBity;
                    }
                }
            }
        }
    }
}

```

```

        }
        pevent->OSEventGrp    |= bity;           (12)
        pevent->OSEventTbl[y] |= bitx;
    }
}
OSTCBPrioTbl[newprio] = ptcb;                    (13)
ptcb->OSTCBPrio        = newprio;                 (14)
ptcb->OSTCBY           = y;                       (15)
ptcb->OSTCBX           = x;
ptcb->OSTCBBitY        = bity;
ptcb->OSTCBBitX        = bitx;
OS_EXIT_CRITICAL();
OSSched();                                           (16)
return (OS_NO_ERR);
} else {
    OSTCBPrioTbl[newprio] = (OS_TCB *)0;           (17)
    OS_EXIT_CRITICAL();
    return (OS_PRIO_ERR);
}
}
}

```

**Listing 4.15, OSTaskChangePrio().**

### ***4.07 Suspending a Task, OSTaskSuspend()***

It is sometimes useful to explicitly suspend the execution of a task. This is accomplished with the **OSTaskSuspend()** function call. A suspended task can only be resumed by calling the **OSTaskResume()** function call. Task suspension is additive. This means that if the task being suspended is also waiting for time to expire then the suspension needs to be removed and the time needs to expire in order for the task to be ready-to-run. A task can either suspend itself or another task.

The code for **OSTaskSuspend()** is shown in listing 4.16. As usual, we check boundary conditions. First, we must ensure that your application is not attempting to suspend the idle task L4.16(1). Next, you must specify a valid priority L4.16(2). Remember that the highest valid priority number (i.e. lowest priority) is **OS\_LOWEST\_PRIO**. Note that you can suspend the statistic task. You may have noticed that the first test L4.16(1) is replicated in L4.16(2). I did this to be backward compatible with  $\mu$ C/OS. The first test could be removed to save a little bit of processing time but, this is really insignificant so I decided to leave it.

Next, we check to see if you specified to suspend the calling task L4.16(3) by specifying **OS\_PRIO\_SELF**. You could also decided to suspend the calling task by specifying its priority L4.16(4). In both of these cases, the scheduler will need to be called. This is why I created the local variable **self** which will be examined at the appropriate time. If we are not suspending the calling task then we will not need to run the scheduler because the calling task is suspending a lower priority task.

We then check to see that the task to suspend exist L4.16(5). If the task to suspend exist, we remove it from the ready list L4.16(6). Note that the task to suspend may not be in the ready list because it's waiting for an event or for time to expire. In this case, the corresponding bit for the task to suspend in **OSRdyTbl[]** would already be cleared (i.e. 0). Clearing it again is faster than checking to see if it's clear and then clearing it if it's not. We then set the **OS\_STAT\_SUSPEND** flag in the task's **OS\_TCB** to indicate that the task is now suspended L4.16(7). Finally, we call the scheduler only if the task being suspended is the calling task L4.16(8).

```

INT8U OSTaskSuspend (INT8U prio)
{
    BOOLEAN    self;
    OS_TCB     *ptcb;

    if (prio == OS_IDLE_PRIO) {                               (1)
        return (OS_TASK_SUSPEND_IDLE);
    }
    if (prio >= OS_LOWEST_PRIO && prio != OS_PRIO_SELF) {      (2)
        return (OS_PRIO_INVALID);
    }
    OS_ENTER_CRITICAL();
    if (prio == OS_PRIO_SELF) {                                (3)
        prio = OSTCBCur->OSTCBPrio;
        self = TRUE;
    } else if (prio == OSTCBCur->OSTCBPrio) {                   (4)
        self = TRUE;
    } else {
        self = FALSE;
    }
    if ((ptcb = OSTCBPrioTbl[prio]) == (OS_TCB *)0) {          (5)
        OS_EXIT_CRITICAL();
        return (OS_TASK_SUSPEND_PRIO);
    } else {
        if ((OSRdyTbl[ptcb->OSTCBY] &= ~ptcb->OSTCBBitX) == 0) { (6)
            OSRdyGrp &= ~ptcb->OSTCBBitY;
        }
        ptcb->OSTCBStat |= OS_STAT_SUSPEND;                    (7)
        OS_EXIT_CRITICAL();
        if (self == TRUE) {                                     (8)
            OSSched();
        }
        return (OS_NO_ERR);
    }
}

```

**Listing 4.16, OSTaskSuspend().**

## 4.08 Resuming a Task, OSTaskResume()

As mentioned in the previous section, a suspended task can only be resumed by calling **OSTaskResume()**. The code for **OSTaskResume()** is shown in listing 4.17. Because we cannot suspend the idle task we must verify that your application is not attempting to resume this task L4.17(1). You will note that this test also ensures that you are not trying to resume **OS\_PRIO\_SELF** (**OS\_PRIO\_SELF** is **#defined** to **0xFF** which is always greater than **OS\_LOWEST\_PRIO**) because this wouldn't make sense.

The task to resume must exist because we will be manipulating its **OS\_TCB** L4.17(2) and, it must also have been suspended L4.17(3). We remove the suspension by clearing the **OS\_STAT\_SUSPEND** bit in the **OSTCBStat** field L4.17(4). For the task to be ready-to-run, the **OSTCBDly** field must be zero L4.17(5) because there are no flags in **OSTCBStat** to indicate that a task is waiting for time to expire. The task is made ready-to-run only when both conditions are satisfied L4.16(6). Finally, the scheduler is called to see if the resumed task has a higher priority than the calling task L4.17(7).

```

INT8U OSTaskResume (INT8U prio)
{
    OS_TCB     *ptcb;

```

```

if (prio >= OS_LOWEST_PRIO) {                                (1)
    return (OS_PRIO_INVALID);
}
OS_ENTER_CRITICAL();
if ((ptcb = OSTCBPrioTbl[prio]) == (OS_TCB *)0) {            (2)
    OS_EXIT_CRITICAL();
    return (OS_TASK_RESUME_PRIO);
} else {
    if (ptcb->OSTCBStat & OS_STAT_SUSPEND) {                  (3)
        if (((ptcb->OSTCBStat & ~OS_STAT_SUSPEND) == OS_STAT_RDY) && (4)
            (ptcb->OSTCBDly == 0)) {                          (5)
            OSRdyGrp |= ptcb->OSTCBBitY;                      (6)
            OSRdyTbl[ptcb->OSTCBY] |= ptcb->OSTCBBitX;
            OS_EXIT_CRITICAL();
            OSSched();                                        (7)
        } else {
            OS_EXIT_CRITICAL();
        }
        return (OS_NO_ERR);
    } else {
        OS_EXIT_CRITICAL();
        return (OS_TASK_NOT_SUSPENDED);
    }
}
}

```

## 4.09 Getting Information about a Task, *OSTaskQuery()*

Your application can obtain information about itself or other application tasks by calling **OSTaskQuery()**. In fact, **OSTaskQuery()** obtains a copy of the contents of the desired task's OS\_TCB. The fields that are available to you in the OS\_TCB depend on the configuration of your application (see **OS\_CFG.H**). Indeed, because  $\mu$ C/OS-II is scalable, it only includes the features that your application requires.

To call **OSTaskQuery()**, your application must allocate storage for an OS\_TCB as shown in listing 4.18. This OS\_TCB is in a totally different data space as the OS\_TCBs allocated by  $\mu$ C/OS-II. After calling **OSTaskQuery()**, this OS\_TCB will contain a snapshot of the OS\_TCB for the desired task. You need to be careful with the links to other OS\_TCBs (i.e. **OSTCBNext** and **OSTCBPrev**); you don't want to change what these links are pointing to! In general, you would only use this function to see what a task is doing – a great tool for debugging.

```

OS_TCB MyTaskData;

void MyTask (void *pdata)
{
    pdata = pdata;
    for (;;) {
        /* User code */
        err = OSTaskQuery(10, &MyTaskData);
        /* Examine error code .. */
        /* User code */
    }
}

```

### Listing 4.18, Obtaining information about a task.

The code for **OSTaskQuery()** is shown in listing 4.19. You should note that I now allow you to examine ALL the tasks, including the idle task L4.19(1). You need to be especially careful NOT to change what **OSTCBNext** and **OSTCBPrev** are pointing to. As usual, we check to see if you want information about the current task L4.19(2) and also, the task must have been created in order to obtain information about it L4.19(3). All fields are copied using the assignment shown instead of field by field L4.19(4). This is much faster because the compiler will most likely generate memory copy instructions.

```

INT8U OSTaskQuery (INT8U prio, OS_TCB *pdata)
{
    OS_TCB *ptcb;

    if (prio > OS_LOWEST_PRIO && prio != OS_PRIO_SELF) {           (1)
        return (OS_PRIO_INVALID);
    }
    OS_ENTER_CRITICAL();
    if (prio == OS_PRIO_SELF) {                                     (2)
        prio = OSTCBCur->OSTCBPrio;
    }
    if ((ptcb = OSTCBPrioTbl[prio]) == (OS_TCB *)0) {              (3)
        OS_EXIT_CRITICAL();
        return (OS_PRIO_ERR);
    }
    *pdata = *ptcb;                                                 (4)
    OS_EXIT_CRITICAL();
    return (OS_NO_ERR);
}

```

### Listing 4.19, OSTaskQuery()

## *Time Management*

We saw in section 3.10 that  $\mu$  C/OS-II (as do other kernels) requires that you provide a periodic interrupt to keep track of time delays and timeouts. This periodic time source is called a *Clock Tick* and should occur between 10 and 100 times per second, or Hertz. The actual frequency of the clock tick depends on the desired tick resolution of your application. However, the higher the frequency of the ticker, the higher the overhead.

Section 3.10 discussed the tick ISR (Interrupt Service Routine) as well as the function that it needs to call to notify  $\mu$ C/OS-II about the tick interrupt, `OSTimeTick()`. This chapter will describe five services that deal with time issues:

- 1) `OSTimeDly()`,
- 2) `OSTimeDlyHMSM()`,
- 3) `OSTimeDlyResume()`,
- 4) `OSTimeGet()` and,
- 5) `OSTimeSet()`.

The functions described in this chapter are found in the file `OS_TIME.C`.

### 5.00 Delaying a task, `OSTimeDly()`

`μC/OS-II` provides a service that allows the calling task to delay itself for a user specified number of clock ticks. This function is called `OSTimeDly()`. Calling this function causes a context switch and forces `μC/OS-II` to execute the next highest priority task that is ready-to-run. The task calling `OSTimeDly()` will be made ready-to-run as soon as the time specified expires or, if another task cancels the delay by calling `OSTimeDlyResume()`. You should note that this task will run only when it's the highest priority task.

Listing 5.1 shows the code for `OSTimeDly()`. As can be seen, your application calls this function by supplying the number of ticks to delay and can be a value between 1 and 65535. If you specify a value of zero L5.1(1), you are indicating that you don't want to delay the task and thus the function will immediately return to the caller. A non zero value will cause `OSTimeDly()` to remove the current task from the ready list L5.1(2). Next, the number of ticks are stored in the `OS_TCB` of the current task L5.1(3) where it will be decremented on every clock tick by `OSTimeTick()`. Finally, since the task is no longer ready, the scheduler is called L5.1(4) so that the next highest priority task that is ready-to-run gets executed.

```
void OSTimeDly (INT16U ticks)
{
    if (ticks > 0) {
        OS_ENTER_CRITICAL();
        if ((OSRdyTbl[OSTCBCur->OSTCBY] &= ~OSTCBCur->OSTCBBitX) == 0) {
            OSRdyGrp &= ~OSTCBCur->OSTCBBitY;
        }
        OSTCBCur->OSTCBDly = ticks;
        OS_EXIT_CRITICAL();
    }
}
```



```

    }
    OSSched();
}

```

( 4 )

### Listing 5.1, OSTimeDly()

It is important to realize that the resolution of a delay is between 0 and 1 tick. In other words, if you try to delay for only one tick, you could end up with a delay between 0 and 1 tick. This is assuming, however, that your processor is not heavily loaded. Figure 5-1 illustrates what happens. A tick interrupt occurs every 10 mS F5-1(1). Assuming that you are not servicing any other interrupts and you have interrupts enabled, the tick ISR will be invoked F5-1(2). You may have a few high priority tasks (i.e. HPTs) that were waiting for time to expire so they will get to execute next F5-1(3). The low priority task (i.e. LPT) shown in figure 5-1 then gets a chance to execute and, upon completion, calls **OSTimeDly(1)** at the moment shown at F5-1(4).  $\mu$  C/OS-II puts the task to sleep until the next tick. When the next tick arrives, the tick ISR executes F5-1(5) but this time, there are no HPTs to execute and thus,  $\mu$  C/OS-II executes the task that delayed itself for 1 tick F5-1(6). As you can see, the task actually delayed for less than one tick! On heavily loaded systems, the task may call **OSTimeDly(1)** a few tens of microseconds before the tick occurs and thus the delay would result in almost no delay because the task would immediately be rescheduled. If your application must delay for *at least* one tick, you must call **OSTimeDly(2)** thus specifying a delay of 2 ticks!

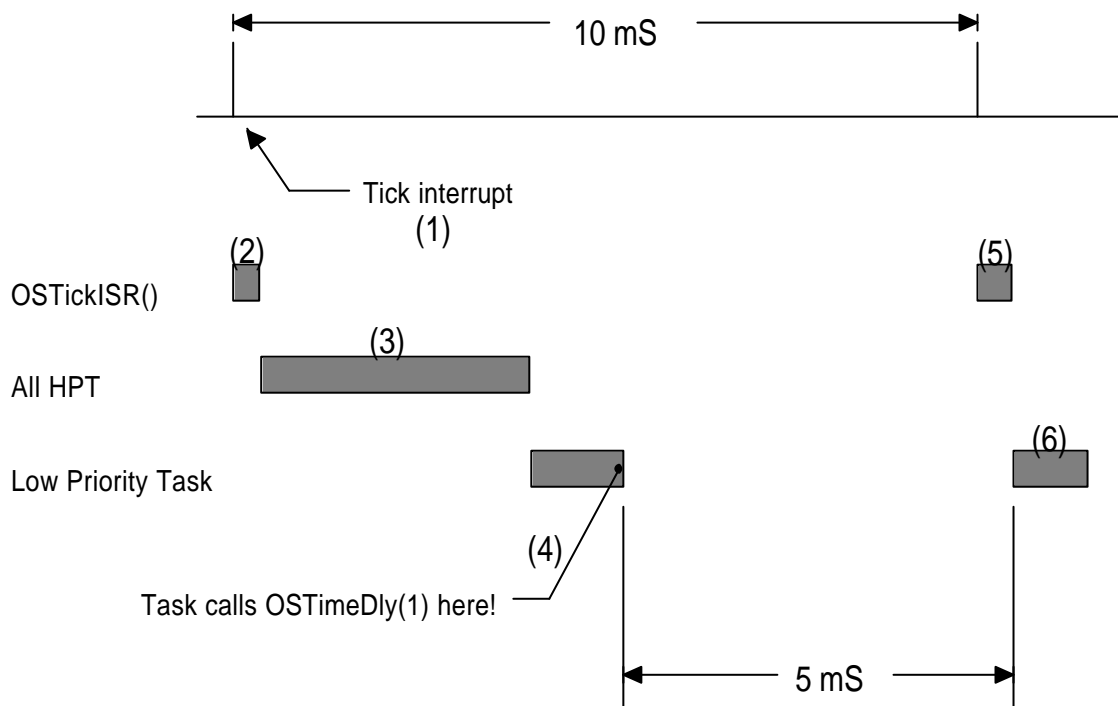


Figure 5-1, Delay resolution

#### 5.01 Delaying a task, OSTimeDlyHMSM()

**OSTimeDly()** is a very useful function but, your application needs to know time in term of ticks. You can use the global **#define** constant **OS\_TICKS\_PER\_SEC** (see **OS\_CFG.H**) to convert time to ticks but this is somewhat awkward. The function **OSTimeDlyHMSM()** has been added so that you can specify time in hours (**H**), minutes (**M**),

seconds (**S**) and milliseconds (**M**) which is more ‘natural’. Like **OSTimeDly()**, calling this function causes a context switch and forces  $\mu$ C/OS-II to execute the next highest priority task that is ready-to-run. The task calling **OSTimeDlyHMSM()** will be made ready-to-run as soon as the time specified expires or if another task cancels the delay by calling **OSTimeDlyResume()** (see section 5.02). Again, this task will run only when it’s the highest priority task.

Listing 5.2 shows the code for **OSTimeDlyHMSM()**. As can be seen, your application calls this function by supplying the delay in **hours**, **minutes**, **seconds** and **milliseconds**. In practice, you should avoid delaying a task for long periods of time because, it’s always a good idea to get some ‘feedback activity’ from a task (incrementing counter, blinking an LED, etc.). If however, you do need long delays,  $\mu$ C/OS-II can delay a task for 256 hours (close to 11 days)!

**OSTimeDlyHMSM()** starts by checking that you have specified valid values for its arguments L5.2(1). As with **OSTimeDly()**, **OSTimeDlyHMSM()** exits if you specify no delay L5.2(9). Because  $\mu$ C/OS-II only knows about ticks, the total number of ticks is computed from the specified time L5.2(3). The code shown in listing 5.2 is obviously not very inefficient. I just showed the equation this way so you can see how the total ticks are computed. The actual code efficiently factors in **OS\_TICKS\_PER\_SEC**. L5.2(3) determines the number of ticks given the specified milliseconds with rounding to the nearest tick. The value **500/OS\_TICKS\_PER\_SECOND** basically correspond to 0.5 tick converted to milliseconds. For example, if the tick rate (i.e. **OS\_TICKS\_PER\_SEC**) is set to 100 Hz (10 mS) then a delay of 4 mS would result in no delay! A delay of 5 mS would result in a delay of 10 mS, etc.

$\mu$ C/OS-II only supports delays of 65535 ticks. To support potentially long delays obtained by L5.2(2), **OSTimeDlyHMSM()** determines how many times we need to delay for more than 65535 ticks L5.2(4) as well as the remaining number of ticks L5.2(5). For example, if **OS\_TICKS\_PER\_SEC** was 100 and you wanted a delay of 15 minutes then **OSTimeDlyHMSM()** would have to delay for  $15 * 60 * 100$  or, 90000 ticks. This delay is broken down into two delays of 32768 ticks (because we can’t do a delay of 65536 ticks, only 65535) and one delay of 24464 ticks. In this case, we would first take care of the remainder L5.2(6) and then, the number of times we exceeded 65536 L5.2(7)-(8) (i.e. done with two 32768 tick delays).

```

INT8U OSTimeDlyHMSM (INT8U hours, INT8U minutes, INT8U seconds, INT16U milli)
{
    INT32U ticks;
    INT16U loops;

    if (hours > 0 || minutes > 0 || seconds > 0 || milli > 0) {          (1)
        if (minutes > 59) {
            return (OS_TIME_INVALID_MINUTES);
        }
        if (seconds > 59) {
            return (OS_TIME_INVALID_SECONDS);
        }
        if (milli > 999) {
            return (OS_TIME_INVALID_MILLI);
        }
        ticks = (INT32U)hours      * 3600L * OS_TICKS_PER_SEC          (2)
              + (INT32U)minutes    *   60L * OS_TICKS_PER_SEC
              + (INT32U)seconds)   *      OS_TICKS_PER_SEC
              + OS_TICKS_PER_SEC * ((INT32U)milli + 500L/OS_TICKS_PER_SEC) / 1000L; (3)
        loops = ticks / 65536L;                                         (4)
        ticks = ticks % 65536L;                                          (5)
        OSTimeDly(ticks);                                                (6)
        while (loops > 0) {
            OSTimeDly(32768);                                           (7)
            OSTimeDly(32768);                                           (8)
            loops--;
        }
        return (OS_NO_ERR);
    }
}

```

```

    } else {
        return (OS_TIME_ZERO_DLY);
    }
}

```

(9)

## Listing 5.2, OSTimeDlyHMSM()

Because of the way **OSTimeDlyHMSM()** is implemented, you cannot resume (see next section) a task that has called **OSTimeDlyHMSM()** with a combined time that exceeds 65535 clock ticks. In other words, if the clock tick runs at 100 Hz then, you will not be able to resume a delayed task that called **OSTimeDlyHMSM(0, 10, 55, 350)** or higher.

### 5.02 Resuming a delayed task, OSTimeDlyResume()

μC/OS-II allows you to resume a task that delayed itself. In other words, instead of waiting for the time to expire, a delayed task can be made ready-to-run by another task which ‘cancels’ the delay. This is done by calling **OSTimeDlyResume()** and specifying the priority of the task to resume. In fact, **OSTimeDlyResume()** can also resume a task that is waiting for an event (see Chapter 6, *Intertask Communication & Synchronization*) although this is not recommended. In this case, the task pending on the event will think it timed out waiting for the event.

```

INT8U OSTimeDlyResume (INT8U prio)
{
    OS_TCB *ptcb;

    if (prio >= OS_LOWEST_PRIO) {
        return (OS_PRIO_INVALID);
    }
    OS_ENTER_CRITICAL();
    ptcb = (OS_TCB *)OSTCBPrioTbl[prio];
    if (ptcb != (OS_TCB *)0) {
        if (ptcb->OSTCBDly != 0) {
            ptcb->OSTCBDly = 0;
            if (!(ptcb->OSTCBStat & OS_STAT_SUSPEND)) {
                OSRdyGrp |= ptcb->OSTCBBity;
                OSRdyTbl[ptcb->OSTCBY] |= ptcb->OSTCBBitX;
                OS_EXIT_CRITICAL();
                OSSched();
            } else {
                OS_EXIT_CRITICAL();
            }
            return (OS_NO_ERR);
        } else {
            OS_EXIT_CRITICAL();
            return (OS_TIME_NOT_DLY);
        }
    } else {
        OS_EXIT_CRITICAL();
        return (OS_TASK_NOT_EXIST);
    }
}

```

## Listing 5.3, Resuming a delayed task.

The code for **OSTimeDlyResume()** is shown in listing 5.3 and starts by making sure you specify a valid priority L5.3(1). Next, we verify that the task to resume does in fact exist L5.3(2). If the task exist, we check to see if the task

is waiting for time to expire L5.3(3). Whenever the **OS\_TCB** field **OSTCBDly** contains a non-zero value, the task is waiting for time to expire, whether because the task called **OSTimedly()**, **OSTimedlyHMSM()** or any of the **PEND** functions described in Chapter 6. The delay is then cancelled by forcing **OSTCBDly** to zero L5.3(4). A delayed task may also have been suspended and thus, the task is only made ready-to-run if the task was not suspended L5.3(5). The task is placed in the ready list when the above conditions are satisfied L5.3(6). At this point, we call the scheduler to see if the resumed task has a higher priority than the current task L5.3(7). This could result in a context switch.

You should note that you could also have a task delay itself by waiting on a semaphore, mailbox or a queue with a timeout (see Chapter 6). You would resume such a task by simply posting to the semaphore, mailbox or queue, respectively. The only problem with this scenario is that it requires that you allocate an event control block (see section 6.00) and thus your application would consume a little bit more RAM.

### ***5.03 System time, OSTimeGet() and OSTimeSet()***

Whenever a clock tick occurs,  $\mu$ C/OS-II increments a 32-bit counter. This counter starts at zero when you initiate multitasking by calling **OSStart()** and rolls over after 4,294,967,295 ticks. At a tick rate of 100 Hz, this 32-bit counter rolls over every 497 days. You can obtain the current value of this counter by calling **OSTimeGet()**. You can also change the value of the counter by calling **OSTimeSet()**. The code for both functions is shown in listing 5.4. Note that interrupts are disabled when accessing **OSTime**. This is because incrementing and copying a 32-bit value on most 8-bit processors requires multiple instructions that must be treated indivisibly.

```
INT32U OSTimeGet (void)
{
    INT32U ticks;

    OS_ENTER_CRITICAL();
    ticks = OSTime;
    OS_EXIT_CRITICAL();
    return (ticks);
}

void OSTimeSet (INT32U ticks)
{
    OS_ENTER_CRITICAL();
    OSTime = ticks;
    OS_EXIT_CRITICAL();
}
```

**Listing 5.4, Obtaining and setting the system time.**

## Chapter 6

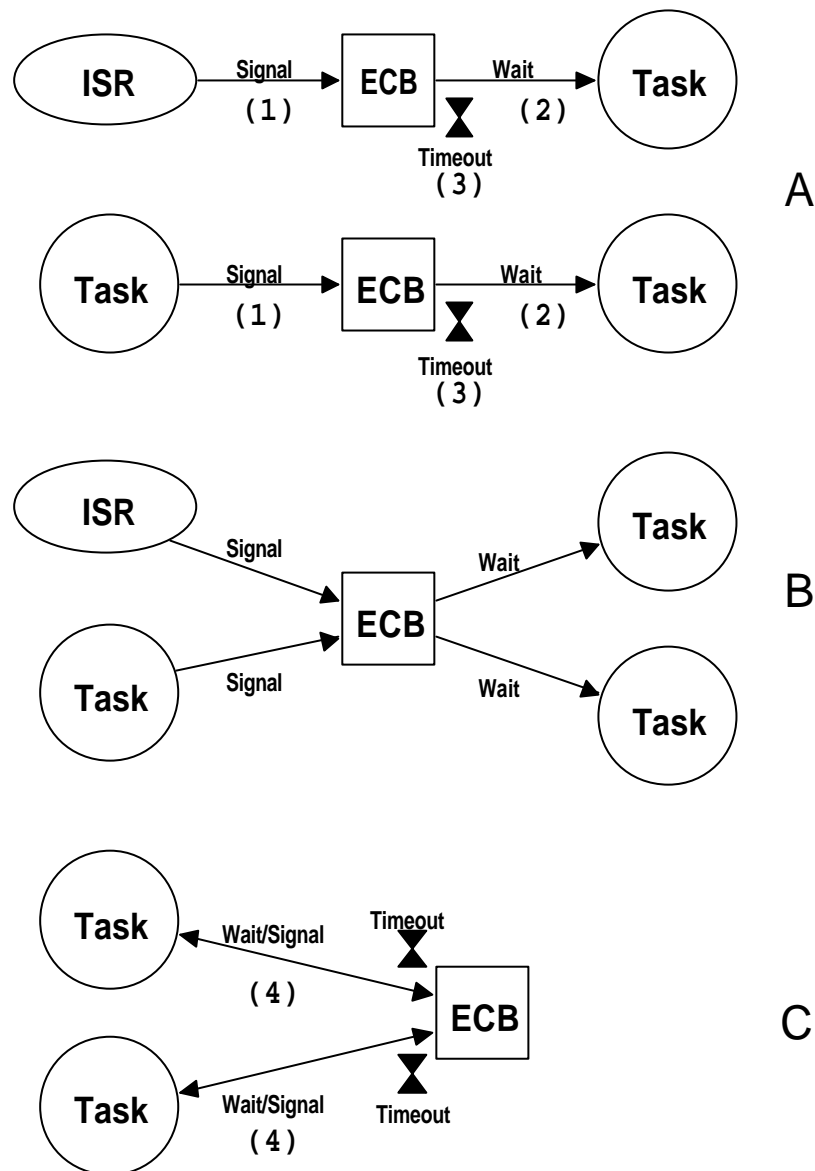
# Intertask Communication & Synchronization

μ C/OS-II provides many mechanisms to protect shared data and provide intertask communication. We have already seen two such mechanisms:

- 1) Disabling and enabling interrupts through the two macros `OS_ENTER_CRITICAL()` and `OS_EXIT_CRITICAL()`, respectively. You use these macros when two tasks or a task and an ISR need to share data. See section 3.00, *Critical Sections*, section 8.03.02, *OS\_CPU.H*, *OS\_ENTER\_CRITICAL()* and *OS\_EXIT\_CRITICAL()* and, section 9.03.02, *OS\_CPU.H*, *Critical Sections*.
- 2) Locking and unlocking μ C/OS-II's scheduler with `OSSchedLock()` and `OSSchedUnlock()`, respectively. Again, you use these services to access shared data. See section 3.06, *Locking and Unlocking the Scheduler*.

This chapter discusses the other three types of services provided by μ C/OS -II: Semaphores, Message mailboxes and Message queues.

Figure 6-1 shows how tasks and Interrupt Service Routines (ISRs) can interact with each other. A task or an ISR *signals* a task F6-1A(1) through a kernel object called an *Event Control Block* (ECB). The signal is considered to be an event which explains my choice of this name. A task can *wait* for another task or an ISR to signal the object F6-1A(2). You should note that only tasks are allowed to wait for events to occur – an ISR is not allowed to wait on an ECB. An optional *timeout* F6-1A(3) can be specified by the waiting task in case the object is not signaled within a specified time period. Multiple tasks can wait for a task or an ISR to signal an ECB F6-1B. When the ECB is signaled, only the highest priority task waiting on the ECB will be ‘signaled’ and thus will be made ready-to-run. An ECB can either be a semaphore, a message mailbox or a message queue as we will see later. When an ECB is used as a semaphore, tasks will both wait and signal the ECB F6-1C(4).



**Figure 6-1, Use of Event Control Blocks.**

## 6.00 Event Control Blocks

μ C/OS-II maintains the state of an ECB in a data structure called **OS\_EVENT** (see uCOS\_II.H). The state of an event consists of the event itself (a counter for a semaphore, a pointer for a message mailbox and an array of pointers for a queue) and, a waiting list for tasks waiting for the event to occur. Each semaphore, mailbox and queue is assigned an ECB. The data structure for an ECB is shown in Listing 6.1.

```
typedef struct {
    void *OSEventPtr; /* Ptr to message or queue structure */
    INT8U OSEventTbl[OS_EVENT_TBL_SIZE]; /* Wait list for event to occur */
    INT16U OSEventCnt; /* Count (when event is a semaphore) */
}
```

```

    INT8U   OSEventType;           /* Event type           */
    INT8U   OSEventGrp;           /* Group for wait list  */
} OS_EVENT;

```

## Listing 6.1, Event Control Block data structure

**OSEventPtr** is only used when the ECB is assigned to a mailbox or a queue. In this case, **OSEventPtr** points to the message when used for a mailbox or a pointer to a message queue data structure (see section 6.06, *Message Mailboxes* and section 6.07, *Message Queues*).

**OSEventTbl[ ]** and **OSEventGrp** are similar to **OSRdyTbl[ ]** and **OSRdyGrp**, respectively except that they contain a list of tasks waiting on the event instead of being a list of tasks ready-to-run (see section 3.04, *Ready List*).

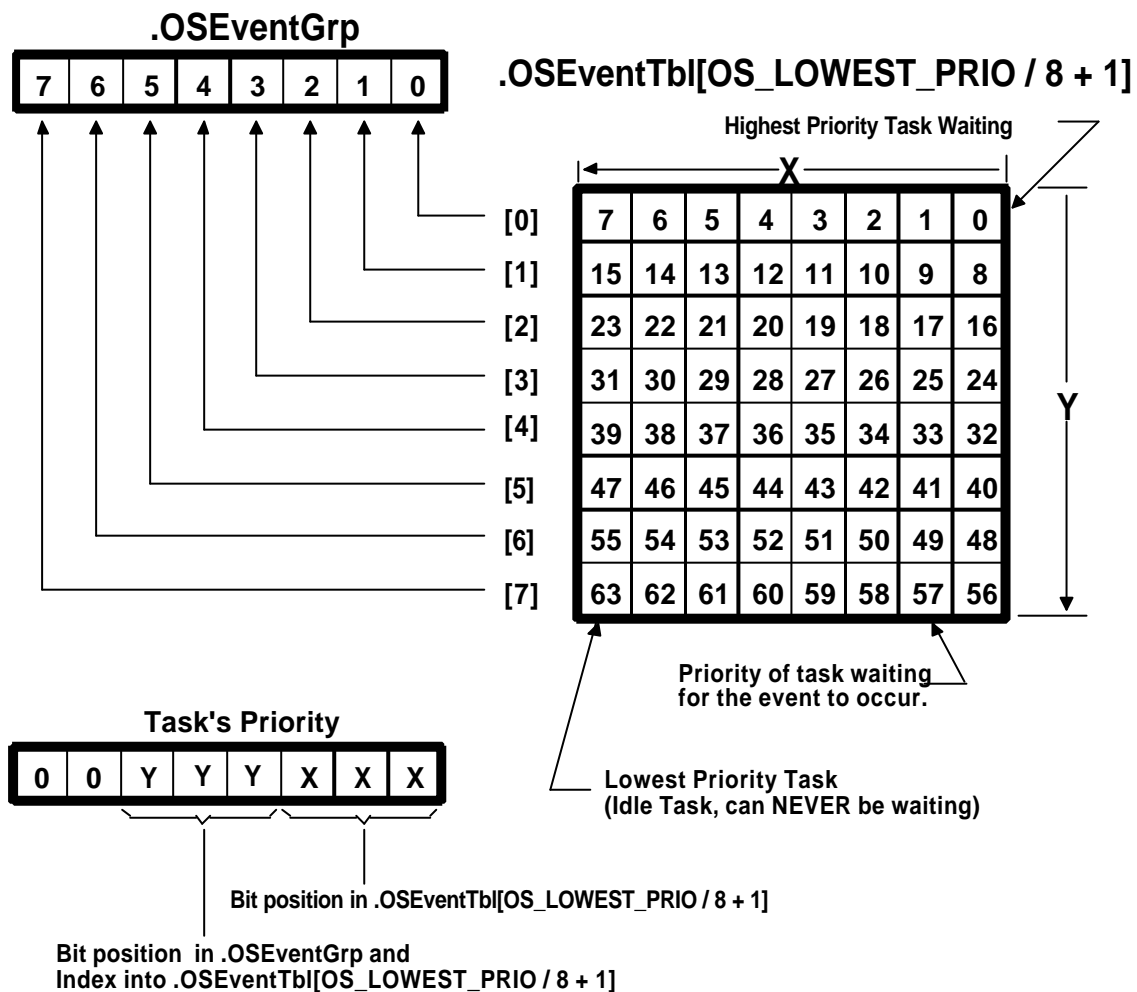
**OSEventCnt** is used to hold the semaphore count when the ECB is used for a semaphore (see section 6.05, *Semaphores*).

**OSEventType** contains the type associated with the ECB and can have the following values: **OS\_EVENT\_SEM**, **OS\_EVENT\_TYPE\_MBOX** or **OS\_EVENT\_TYPE\_Q**. This field is used to make sure you are accessing the proper object when you perform operations on these objects through  $\mu$ C/OS-II's service calls.

Each task that needs to wait for the event to occur is placed in the wait list consisting of the two variables, **.OSEventGrp** and **.OSEventTbl[ ]**. Note that I used a dot (i.e. **.**) in front of the variable name to indicate that the variable is part of a data structure. Task priorities are grouped (8 tasks per group) in **.OSEventGrp**. Each bit in **.OSEventGrp** is used to indicate whenever any task in a group is waiting for the event to occur. When a task is waiting, its corresponding bit is set in the wait table, **.OSEventTbl[ ]**. The size (in bytes) of **.OSEventTbl[ ]** depends on **OS\_LOWEST\_PRIO** (see **uCOS\_II.H**). This allows  $\mu$ C/OS-II to reduce the amount of RAM (i.e. data space) when your application requires just a few task priorities.

The task that will be resumed when the event occurs is the highest priority task waiting for the event and corresponds to the lowest priority number which has a bit set in **.OSEventTbl[ ]**. The relationship between **.OSEventGrp** and **.OSEventTbl[ ]** is shown in Figure 6-2 and is given by the following rules:

Bit 0 in `.OSEventGrp` is 1 when any bit in `.OSEventTbl[0]` is 1.  
 Bit 1 in `.OSEventGrp` is 1 when any bit in `.OSEventTbl[1]` is 1.  
 Bit 2 in `.OSEventGrp` is 1 when any bit in `.OSEventTbl[2]` is 1.  
 Bit 3 in `.OSEventGrp` is 1 when any bit in `.OSEventTbl[3]` is 1.  
 Bit 4 in `.OSEventGrp` is 1 when any bit in `.OSEventTbl[4]` is 1.  
 Bit 5 in `.OSEventGrp` is 1 when any bit in `.OSEventTbl[5]` is 1.  
 Bit 6 in `.OSEventGrp` is 1 when any bit in `.OSEventTbl[6]` is 1.  
 Bit 7 in `.OSEventGrp` is 1 when any bit in `.OSEventTbl[7]` is 1.



**Figure 6-2, Wait list for task waiting for an event to occur.**

The following piece of code is used to place a task in the wait list list:

```
pevent->OSEventGrp      |= OSMaTbl[prio >> 3];
pevent->OSEventTbl[prio >> 3] |= OSMaTbl[prio & 0x07];
```

**Listing 6.2, Making a task wait for an event.**



**prio** is the task's priority and **pevent** is a pointer to the event control block.

You should realize from listing 6.2 that inserting a task in the wait list always takes the same amount of time and does not depend on how many tasks are in your system. Also, from Figure 6-2, the lower 3 bits of the task's priority are used to determine the bit position in **.OSEventTbl[ ]**, while the next three most significant bits are used to determine the index into **.OSEventTbl[ ]**. Note that **OSMapTbl[ ]** (see **OS\_CORE.C**) is a table in ROM, used to equate an index from 0 to 7 to a bit mask as shown in the table 6.1.

Index	Bit mask (Binary)
0	00000001
1	00000010
2	00000100
3	00001000
4	00010000
5	00100000
6	01000000
7	10000000

**Table 6.1, Contents of OSMapTbl[ ].**

A task is removed from the wait list by reversing the process. The following code is executed in this case:

```
if ((pevent->OSEventTbl[prio >> 3] &= ~OSMapTbl[prio & 0x07]) == 0) {  
    pevent->OSEventGrp &= ~OSMapTbl[prio >> 3];  
}
```

### **Listing 6.3, Removing a task from a wait list.**

This code clears the bit corresponding to the task in **.OSEventTbl[ ]** and clears the bit in **.OSEventGrp** only if all tasks in a group are not waiting, i.e. all bits in **.OSEventTbl[prio >> 3]** are 0. Another table lookup is performed, rather than scanning through the table starting with **.OSEventTbl[0]**, to find the highest priority task that is waiting for the event. **OSUnMapTbl[256]** is a priority resolution table (see **OS\_CORE.C**). Eight bits are used to represent when tasks are waiting in a group. The least significant bit has the highest priority. Using this byte to index the table returns the bit position of the highest priority bit set, a number between 0 and 7. Determining the priority of the highest priority task waiting for the event is accomplished with the following section of code:

```

y   = OSUnMapTbl[pevent->OSEventGrp];
x   = OSUnMapTbl[pevent->OSEventTbl[y]];
prio = (y << 3) + x;

```

### Listing 6.4, Finding the highest priority task waiting for the event.

For example, if `.OSEventGrp` contains 01101000 (binary) then the table lookup `OSUnMapTbl[.OSEventGrp]` would yield a value of 3, which corresponds to bit #3 in `.OSEventGrp`. Notes that bit positions are assumed to start on the right with bit #0 being the rightmost bit. Similarly, if `.OSEventTbl[3]` contained 11100100 (binary) then `OSUnMapTbl[.OSEventTbl[3]]` would result in a value of 2 (i.e. bit #2). The priority of the task waiting (`prio`) would then be 26 ( $3 * 8 + 2$ )!

The number of ECBs to allocate depends on the number of semaphores, mailboxes and queues needed for your application. The number of ECBs is established by the `#define OS_MAX_EVENTS` which you define in `OS_CFG.H`. When `OSInit()` is called (see section 3.11), all ECBs are linked in a singly linked list - the list of free ECBs (see figure 63). When a semaphore, mailbox or queue is created, an ECB is removed from this list and initialized. ECBs cannot be returned to the list of free ECB because semaphores, mailboxes and queues cannot be deleted.

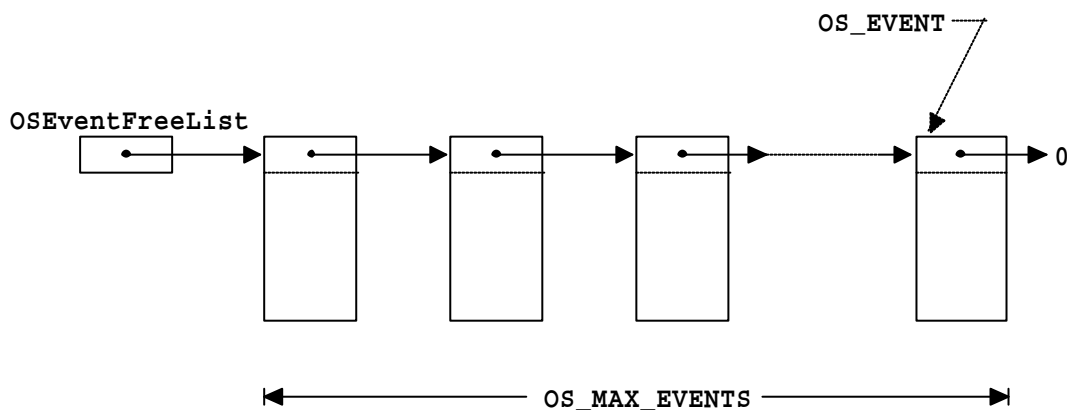


Figure 6-3, List of free ECBs.

There are four common operations that can be performed on ECBs:

- 1) Initialize an ECB
- 2) Make a task ready
- 3) Make a task wait for an event
- 4) Make a task ready because a timeout occurred while waiting for an event.

To avoid duplicating code and thus to reduce code size, four functions have been created to perform these operations: `OSEventWaitListInit()`, `OSEventTaskRdy()`, `OSEventWait()` and `OSEventTO()`, respectively.

## 6.01 Initializing an ECB, `OSEventWaitListInit()`

Listing 6.5 shows the code for `OSEventWaitListInit()` which is a function called when a semaphore, message mailbox or a message queue is created (see `OSSemCreate()`, `OSMboxCreate()` or `OSQCreate()`). All we are

trying to accomplish in `OSEventWaitListInit()` is to indicate that no task is waiting on the ECB. `OSEventWaitListInit()` is passed a pointer to an event control block which is assigned when the semaphore, message mailbox or message queue is created.

```
void OSEventWaitListInit (OS_EVENT *pevent)
{
    INT8U i;

    pevent->OSEventGrp = 0x00;
    for (i = 0; i < OS_EVENT_TBL_SIZE; i++) {
        pevent->OSEventTbl[i] = 0x00;
    }
}
```

### Listing 6.5, Initializing the wait list.

## 6.02 Making a task ready, *OSEventTaskRdy()*

Listing 6.6 shows the code for `OSEventTaskRdy()`. This function is called by `OSSemPost()`, `OSMboxPost()`, `OSQPost()` and `OSQPostFront()` when an ECB is signaled and the highest priority task waiting on the ECB needs to be made ready-to-run. In other words, `OSEventTaskRdy()` removes the highest priority task (HPT) from the wait list of the ECB and makes this task ready-to-run. Figure 6-4 is used to illustrate the first four operation performed in `OSEventTaskRdy()`.

`OSEventTaskRdy()` starts by determining the index into the `.OSEventRdyTbl[]` of the HPT L6.6/F6-4(1), a number between 0 and `OS_LOWEST_PRIO/8+1`. The bit mask of the HPT in `.OSEventGrp` is then obtained L6.6/F6-4(2), see table 6.1 for possible values. We then determine the bit position of the task in `.OSEventTbl[]` L6.6/F6-4(3), a value between 0 and `OS_LOWEST_PRIO/8+1`. Next, the bit mask of the HPT in `.OSEventTbl[]` is determined L6.6/F6-4(4), see table 6.1 for possible values. The priority of the task being made ready-to-run is determined by combining the x and y indexes L6.6(5). At this point, we can now extract the task from the wait list L6.6(6).

The Task Control Block (TCB) of the task being readied contains information that also needs to be changed. We can thus obtain a pointer to that TCB knowing the task's priority L6.6(7). Because the HPT is not waiting anymore, we need to make sure that `OSTimeTick()` will not attempt to decrement the `.OSTCBDly` value of that task. We prevent this by forcing this field to 0 L6.6(8). We then force the pointer to the ECB to `NULL` because the HPT will no longer be waiting on this ECB L6.6(9). A message is sent to the HPT if `OSEventTaskRdy()` is called by either `OSMboxPost()` or `OSQPost()`. This message is passed as an argument and needs to be placed in the task's TCB L6.6(10). When `OSEventTaskRdy()` is called, the `msk` argument contains the appropriate bit mask to clear the bit in `.OSTCBStat` which corresponds to the type of event signaled (`OS_STAT_SEM`, `OS_STAT_MBOX` or `OS_STAT_Q`, see `uCOS_II.H`) L6.6(11). Finally, if the `.OSTCBStat` indicates that the task is ready-to-run L6.6(12), we insert this task in  $\mu$ C/OS-II's ready list L6.6(13). Note that the task may not be ready-to-run because it could have been explicitly suspended (see section 4.07, *Suspending a Task*, `OSTaskSuspend()` and section 4.08, *Resuming a Task*, `OSTaskResume()`).

You should note that `OSEventTaskRdy()` is called with interrupts disabled.

```
void OSEventTaskRdy (OS_EVENT *pevent, void *msg, INT8U msk)
{
    OS_TCB *ptcb;
    INT8U x;
    INT8U y;
    INT8U bitx;
    INT8U bity;
```

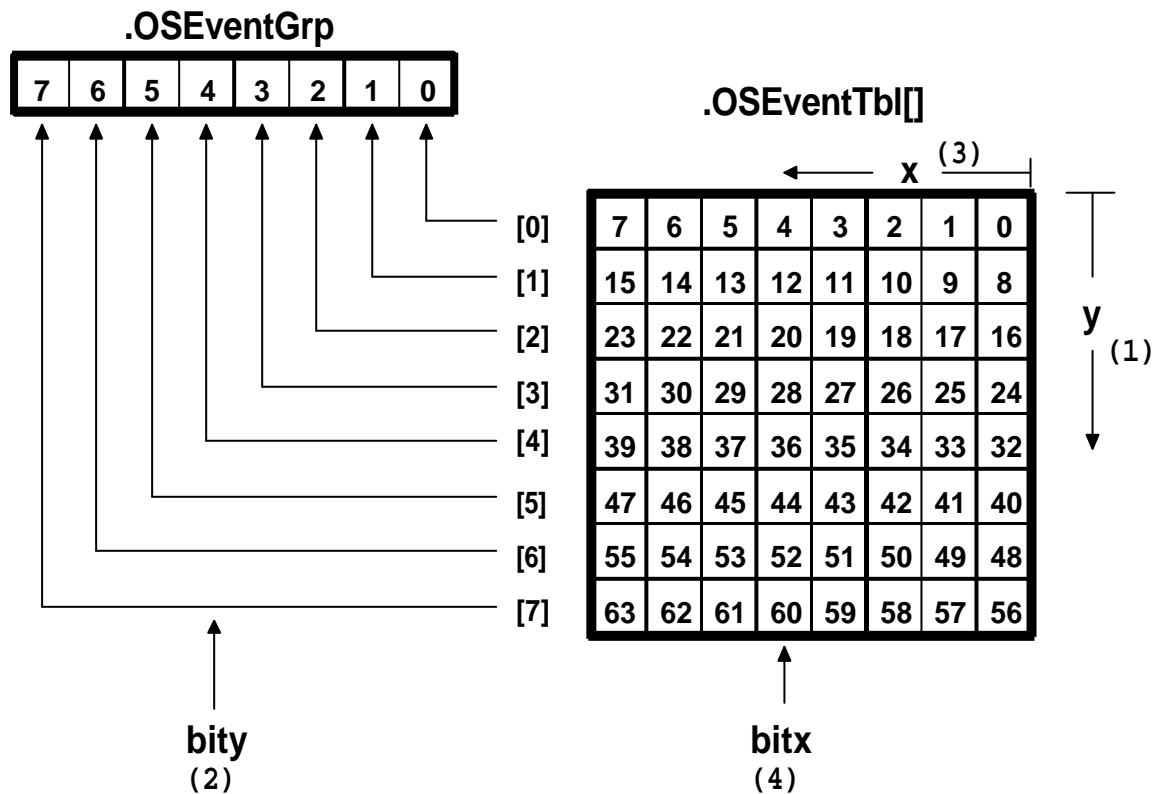
```

INT8U    prio;

y    = OSUnMapTbl[pevent->OSEventGrp];           (1)
bity = OSMaTbl[y];                               (2)
x    = OSUnMapTbl[pevent->OSEventTbl[y]];         (3)
bitx = OSMaTbl[x];                               (4)
prio = (INT8U)((y << 3) + x);                     (5)
if ((pevent->OSEventTbl[y] & ~bitx) == 0) {        (6)
    pevent->OSEventGrp &= ~bity;
}
ptcb          = OSTCBPrioTbl[prio];               (7)
ptcb->OSTCBDly  = 0;                              (8)
ptcb->OSTCBEvtPtr = (OS_EVENT *)0;                 (9)
#if (OS_Q_EN && (OS_MAX_QS >= 2)) || OS_MBOX_EN
ptcb->OSTCBMsg   = msg;                           (10)
#else
msg             = msg;
#endif
ptcb->OSTCBStat  &= ~msk;                          (11)
if (ptcb->OSTCBStat == OS_STAT_RDY) {              (12)
    OSRdyGrp    |= bity;                          (13)
    OSRdyTbl[y] |= bitx;
}
}

```

**Listing 6.6, Making a task ready-to-run.**



**Figure 6-4, Making a task ready-to-run.**

### 6.03 Making a task wait for an event, *OSEventTaskWait()*

Listing 6.7 shows the code for `OSEventTaskWait()`. This function is called by `OSSemPend()`, `OSMboxPend()` and `OSQPend()` when a task must wait on an ECB. In other words, `OSEventTaskWait()` removes the current task from the ready list and places this task in the wait list of the ECB.

```
void OSEventTaskWait (OS_EVENT *pevent)
{
    OSTCBCur->OSTCBEventPtr = pevent;                (1)
    if ((OSRdyTbl[OSTCBCur->OSTCBY] &= ~OSTCBCur->OSTCBBitX) == 0) { (2)
        OSRdyGrp &= ~OSTCBCur->OSTCBBitY;
    }
    pevent->OSEventTbl[OSTCBCur->OSTCBY] |= OSTCBCur->OSTCBBitX;    (3)
    pevent->OSEventGrp |= OSTCBCur->OSTCBBitY;
}
```

**Listing 6.7, Making a task wait on an ECB.**

The pointer to the ECB is placed in the task's TCB to link the task to the event control block L6.7(1). Next, the task is removed from the ready list L6.7(2) and placed in the wait list for the ECB L6.7(3).

### 6.04 Making a task ready because of a timeout, *OSEventTO()*

Listing 6.8 shows the code for `OSEventTO()`. This function is called by `OSSemPend()`, `OSMboxPend()` and `OSQPend()` when a task has been made ready-to-run by `OSTimeTick()` which means that the ECB was not signaled within the specified timeout period. In this case, we must remove the task from the wait list of the ECB L6.8(1) and mark the task as being ready L6.8(2). Finally, the link to the ECB is removed from the task's TCB L6.8(3). You should note that `OSEventTO()` is also called with interrupts disabled.

```
void OSEventTO (OS_EVENT *pevent)
{
    if ((pevent->OSEventTbl[OSTCBCur->OSTCBY] &= ~OSTCBCur->OSTCBBitX) == 0) { (1)
        pevent->OSEventGrp &= ~OSTCBCur->OSTCBBitY;
    }
    OSTCBCur->OSTCBStat = OS_STAT_RDY;                (2)
    OSTCBCur->OSTCBEventPtr = (OS_EVENT *)0;          (3)
}
```

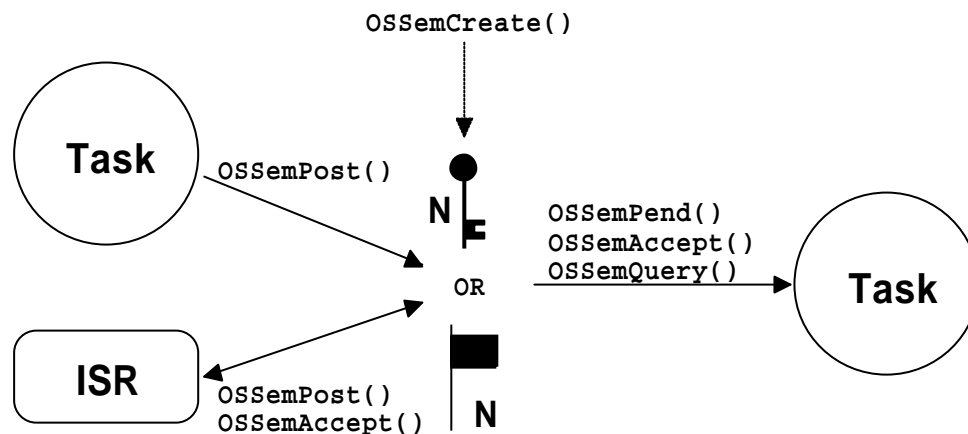
**Listing 6.8, Making a task ready because of a timeout.**

### 6.05 Semaphores

μC/OS-II's semaphores consist of two elements: a 16-bit unsigned integer used to hold the semaphore count (0..65535), and a list of tasks waiting for the semaphore count to be greater than 0. To enable μC/OS-II's semaphore services, you must set the configuration constant `OS_SEM_EN` to 1 (see file `OS_CFG.H`).

A semaphore needs to be created before it can be used. Creating a semaphore is accomplished by calling `OSSemCreate()` (see next section) and specifying the initial count of the semaphore. The initial value of a semaphore can be between 0 and 65535. If you use the semaphore to signal the occurrence of one or more events then you would typically initialize the semaphore to 0. If you use the semaphore to access a shared resource then you would initialize the semaphore to 1 (i.e. use it as a *binary* semaphore). Finally, if the semaphore allows your application to obtain any one of 'n' identical resources then, you would initialize the semaphore to 'n'. The semaphore would then be used as a *counting* semaphore.

$\mu$ C/OS-II provides five services to access semaphores: `OSSemCreate()`, `OSSemPend()`, `OSSemPost()`, `OSSemAccept()` and `OSSemQuery()`. Figure 6-5 shows a flow diagram to illustrate the relationship between tasks, ISRs and a semaphore. Note that the symbology used to represent a semaphore is either a 'key' or a 'flag'. You would use a 'key' symbol if the semaphore was used to access shared resources. The 'N' next to the key represents how many resources are available for the resource. 'N' would be 1 for a binary semaphore. You would use a 'flag' symbol when a semaphore is used to signal the occurrence of an event. 'N' in this case represents the number of times the event can be signaled. As you can see from figure 6-5, a task or an ISR can call `OSSemPost()`. However, only tasks are allowed to call `OSSemPend()` and `OSSemQuery()`.



**Figure 6-5, Relationship between tasks, ISRs and a semaphore.**

### 6.05.01 Creating a Semaphore, `OSSemCreate()`

The code to create a semaphore is shown in listing 6.9. `OSSemCreate()` starts by obtaining an ECB from the free list of ECBs (see figure 6-3) L6.9(1). The linked list of free ECBs is adjusted to point to the next free ECB L6.9(2). If there was an ECB available L6.9(3), the ECB type is set to `OS_EVENT_TYPE_SEM` L6.9(4). Other `OSSem???` function calls will check this field to make sure that the ECB is of the proper type. This prevents you from calling `OSSemPost()` on an ECB that was created for use as a message mailbox (see section 6.06). Next the desired initial count for the semaphore is stored in the ECB L6.9(5). The wait list is then initialized by calling `OSEventWaitListInit()` (see section 6.01, *Initializing an ECB, OSEventWaitListInit()*) L6.9(6). Because the semaphore is being initialized, there are no tasks waiting for it. Finally, `OSSemCreate()` returns a pointer to the ECB L6.9(7). This pointer MUST be used in subsequent calls to manipulate semaphores `OSSemPend()`, `OSSemPost()`, `OSSemAccept()` and `OSSemQuery()`. The pointer is basically used as the semaphore's handle. If there were no more ECBs, `OSSemCreate()` would have returned a **NULL** pointer.

You should note that once a semaphore has been created, it cannot be deleted. In other words, there is no way in  $\mu$ C/OS-II to return an ECB back to the free list of ECBs. It would be 'dangerous' to delete a semaphore object if tasks were waiting on the semaphore and/or relying on the presence of the semaphore. What would those tasks do?

```
OS_EVENT *OSSemCreate (INT16U cnt)
{
    OS_EVENT *pevent;

    OS_ENTER_CRITICAL();
    pevent = OSEventFreeList;
```

(1)

```

    if (OSEventFreeList != (OS_EVENT *)0) { (2)
        OSEventFreeList = (OS_EVENT *)OSEventFreeList->OSEventPtr;
    }
    OS_EXIT_CRITICAL();
    if (pevent != (OS_EVENT *)0) { (3)
        pevent->OSEventType = OS_EVENT_TYPE_SEM; (4)
        pevent->OSEventCnt = cnt; (5)
        OSEventWaitListInit(pevent); (6)
    }
    return (pevent); (7)
}

```

### Listing 6.9, Creating a semaphore.

#### 6.05.02 Waiting on a Semaphore, *OSSemPend()*

The code to wait on a semaphore is shown in listing 6.10. **OSSemPend()** starts by checking that the ECB being pointed to by **pevent** has been created by **OSSemCreate()** L6.10(1). If the semaphore is available (its count is non-zero) L6.10(2) then the count is decremented L6.10(3), and the function return to its caller with an error code indicating success. Obviously, if you want the semaphore, this is the outcome you are looking for. This also happens to be the fastest path through **OSSemPend()**.

If the semaphore is not available (the count is zero) then we check to see if the function was called by an ISR L6.10(4). Under normal circumstances, you should not call **OSSemPend()** from an ISR because an ISR cannot be made to wait. I decided to add this check just in case. However, if the semaphore is in fact available, the call to **OSSemPend()** would be successful even if called by an ISR!

If the semaphore count is zero and **OSSemPend()** was not called by an ISR then the calling task needs to be put to sleep until another task (or an ISR) signals the semaphore (see the next section). **OSSemPend()** allows you to specify a timeout value as one of its arguments (i.e. **timeout**). This feature is useful to avoid waiting indefinitely for the semaphore. If the value passed is non-zero, then **OSSemPend()** will suspend the task until the semaphore is signaled or the specified timeout period expires. Note that a **timeout** value of 0 indicates that the task is willing to wait forever for the semaphore to be signaled. To put the calling task to sleep, **OSSemPend()** sets the status flag in the task's TCB (Task Control Block) to indicate that the task is suspended waiting for a semaphore L6.10(5). The timeout is also stored in the TCB L6.10(6) so that it can be decremented by **OSTimeTick()**. You should recall (see section 3.10, *Clock Tick*) that **OSTimeTick()** decrements each of the created task's **.OSTCBDly** field if it's non-zero. The actual work of putting the task to sleep is done by **OSEventTaskWait()** (see section 6.03, *Making a task wait for an event, OSEventTaskWait()*) L6.10(7).

Because the calling task is no longer ready-to-run, the scheduler is called to run the next highest priority task that is ready-to-run L6.10(8). When the semaphore is signaled (or the timeout period expired) and the task that called **OSSemPend()** is again the highest priority task then **OSSched()** returns. **OSSemPend()** then checks to see if the TCB's status flag is still set to indicate that the task is waiting for the semaphore L6.10(9). If the task is still waiting for the semaphore then it must not have been signaled by an **OSSemPost()** call. Indeed, the task must have been readied by **OSTimeTick()** indicating that the timeout period has expired. In this case, the task is removed from the wait list for the semaphore by calling **OSEventTO()** L6.10(10), and an error code is returned to the task that called **OSSemPend()** to indicate that a timeout occurred. If the status flag in the task's TCB doesn't have the **OS\_STAT\_SEM** bit set then the semaphore must have been signaled and the task that called **OSSemPend()** can now conclude that it has the semaphore. Also, the link to the ECB is removed L6.10(11).

```

void OSEventTaskWait(OS_EVENT *pevent, INT16U timeout, INT8U *err)
{
    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_SEM) { (1)
        OS_EXIT_CRITICAL();
    }
}

```





```

        return (OS_NO_ERR);
    } else {
        if (pevent->OSEventCnt < 65535) {
            pevent->OSEventCnt++;
            OS_EXIT_CRITICAL();
            return (OS_NO_ERR);
        } else {
            OS_EXIT_CRITICAL();
            return (OS_SEM_OVF);
        }
    }
}

```

**Listing 6.11, Signaling a semaphore.**

#### ***6.05.04 Getting a Semaphore without waiting, OS\_SemAccept()***

It is possible to obtain a semaphore without putting a task to sleep if the semaphore is not available. This is accomplished by calling **OS\_SemAccept()** and the code for this function is shown in listing 6.12. **OS\_SemAccept()** starts by checking that the ECB being pointed to by **pevent** has been created by **OS\_SemCreate()** L6.12(1). **OS\_SemAccept()** then gets the current semaphore count L6.12(2) to determine whether the semaphore is available (i.e. non-zero value indicates available) L6.12(3). The count is decremented only if the semaphore was available L6.12(4). Finally, the original count of the semaphore is returned to the caller L6.12(5). The code that called **OS\_SemAccept()** will need to examine the returned value. A returned value of zero indicates that the semaphore was not available while a non-zero value indicates that the semaphore was available. Furthermore, a non-zero value indicates to the caller the number of resources that was available. Keep in mind that in this case, one of the resources has been allocated to the calling task because the count has been decremented. An ISR should use **OS\_SemAccept()** instead of **OS\_SemPend()**.

```

INT16U OS_SemAccept (OS_EVENT *pevent)
{
    INT16U cnt;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_SEM) {
        OS_EXIT_CRITICAL();
        return (0);
    }
    cnt = pevent->OSEventCnt;
    if (cnt > 0) {
        pevent->OSEventCnt--;
    }
    OS_EXIT_CRITICAL();
    return (cnt);
}

```

**Listing 6.12, Getting a semaphore without waiting.**

#### ***6.05.05 Obtaining the status of a semaphore, OS\_SemQuery()***

**OS\_SemQuery()** allows your application to take a 'snapshot' of an ECB that is used as a semaphore. The code for this function is shown in listing 6.13. **OS\_SemQuery()** is passed two arguments: **pevent** contains a pointer to the semaphore which is returned by **OS\_SemCreate()** when the semaphore is created and, **pdata** which is a pointer to a data structure **OS\_SEM\_DATA**, see **uCOS\_II.H**) that will hold information about the semaphore. Your

application will thus need to allocate a variable of type `OS_SEM_DATA` that will be used to receive the information about the desired semaphore. I decided to use a new data structure because the caller should only be concerned with semaphore specific data as opposed to the more generic `OS_EVENT` data structure which contain two additional fields (i.e. `.OSEventType` and `.OSEventPtr`). `OS_SEM_DATA` contains the current semaphore count (`.OSCnt`) and the list of tasks waiting on the semaphore (`.OSEventTbl[]` and `.OSEventGrp`).

As always, our function checks that `pevent` points to an ECB containing a semaphore L6.13(1). `OSSemQuery()` then copies the wait list L6.13(2) followed by the current semaphore count L6.13(3) from the `OS_EVENT` structure to the `OS_SEM_DATA` structure.

```

INT8U OSSemQuery (OS_EVENT *pevent, OS_SEM_DATA *pdata)
{
    INT8U i;
    INT8U *psrc;
    INT8U *pdest;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_SEM) {                (1)
        OS_EXIT_CRITICAL();
        return (OS_ERR_EVENT_TYPE);
    }
    pdata->OSEventGrp = pevent->OSEventGrp;                          (2)
    psrc               = &pevent->OSEventTbl[0];
    pdest              = &pdata->OSEventTbl[0];
    for (i = 0; i < OS_EVENT_TBL_SIZE; i++) {
        *pdest++ = *psrc++;
    }
    pdata->OSCnt        = pevent->OSEventCnt;                        (3)
    OS_EXIT_CRITICAL();
    return (OS_NO_ERR);
}

```

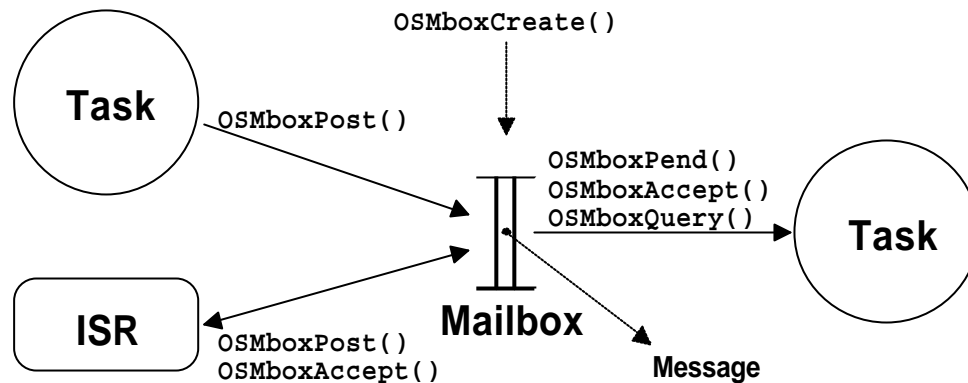
**Listing 6.13, Obtaining the status of a semaphore.**

## 6.06 Message Mailboxes

A message mailbox (or simply a mailbox) is a  $\mu$ C/OS-II object that allows a task or an ISR to send a pointer size variable to another task. The pointer would typically be initialized to point to some application specific data structure containing a 'message'. To enable  $\mu$ C/OS-II's message mailbox services, you must set the configuration constant `OS_MBOX_EN` to 1 (see file `OS_CFG.H`).

A mailbox needs to be created before it can be used. Creating a mailbox is accomplished by calling `OSMboxCreate()` (see next section) and specifying the initial value of the pointer. Typically, the initial value is a **NULL** pointer but a mailbox can initially contain a message. If you use the mailbox to signal the occurrence of an event (i.e. send a message) then you would typically initialize it to a **NULL** pointer because the event (most likely) would not have occurred. If you use the mailbox to access a shared resource then you would initialize the mailbox with a non-**NULL** pointer. In this case, you would basically use the mailbox as a *binary* semaphore.

$\mu$ C/OS-II provides five services to access mailboxes: `OSMboxCreate()`, `OSMboxPend()`, `OSMboxPost()`, `OSMboxAccept()` and `OSMboxQuery()`. Figure 6-6 shows a flow diagram to illustrate the relationship between tasks, ISRs and a message mailbox. Note that the symbology used to represent a mailbox is an I-beam. The content of the mailbox is a pointer to a message. What the pointer points to is application specific. A mailbox can only contain one pointer (mailbox is full) or a pointer to **NULL** (mailbox is empty). As you can see from figure 6-6, a task or an ISR can call `OSMboxPost()`. However, only tasks are allowed to call `OSMboxPend()` and `OSMboxQuery()`.



**Figure 6-6, Relationship between tasks, ISRs and a message mailbox.**

### 6.06.01 Creating a Mailbox, *OSMboxCreate()*

The code to create a mailbox is shown in listing 6.14 and is basically identical to `OSSemCreate()` except that the ECB type is set to `OS_EVENT_TYPE_MBOX` L6.14(1) and, instead of using the `.OSEventCnt` field, we use the `.OSEventPtr` field to hold the message pointer L6.14(2).

`OSMboxCreate()` returns a pointer to the ECB L6.14(3). This pointer **MUST** be used in subsequent calls to access the mailbox (`OSMboxPend()`, `OSMboxPost()`, `OSMboxAccept()` and `OSMboxQuery()`). The pointer is basically used as the mailbox handle. Note that if there were no more ECBs, `OSMboxCreate()` would have returned a **NULL** pointer.

You should note that once a mailbox has been created, it cannot be deleted. It would be ‘dangerous’ to delete a message mailbox object if tasks were waiting on the mailbox.

```

OS_EVENT *OSMboxCreate (void *msg)
{
    OS_EVENT *pevent;

    OS_ENTER_CRITICAL();
    pevent = OSEventFreeList;
    if (OSEventFreeList != (OS_EVENT *)0) {
        OSEventFreeList = (OS_EVENT *)OSEventFreeList->OSEventPtr;
    }
    OS_EXIT_CRITICAL();
    if (pevent != (OS_EVENT *)0) {
        pevent->OSEventType = OS_EVENT_TYPE_MBOX;           (1)
        pevent->OSEventPtr = msg;                           (2)
        OSEventWaitListInit(pevent);
    }
    return (pevent);                                       (3)
}

```

**Listing 6.14, Creating a mailbox.**

## 6.06.02 Waiting for a message at a Mailbox, OSMboxPend()

The code to wait for a message to arrive at a mailbox is shown in listing 6.15. Again, the code is very similar to `OSSemPend()` so I will only discuss the differences. `OSMboxPend()` verifies that the ECB being pointed to by `pevent` has been created by `OSMboxCreate()` L6.15(1). A message is available when `.OSEventPtr` contains a non-`NULL` pointer L6.15(2). In this case, `OSMboxPend()` stores the pointer to the message in `msg` and places a `NULL`-pointer in `.OSEventPtr` to empty the mailbox L6.15(3). Again, this is the outcome you are looking for. This also happens to be the fastest path through `OSMboxPend()`.

If a message is not available (`.OSEventPtr` contains a `NULL`-pointer), we check to see if the function was called by an ISR L6.15(4). As with `OSSemPend()`, you should not call `OSMboxPend()` from an ISR because an ISR cannot be made to wait. Again, I decided to add this check just in case. However, if the message is in fact available, the call to `OSMboxPend()` would be successful even if called from an ISR!

If a message is not available then the calling task must be suspended until either a message is posted or the specified timeout period expires L6.15(5). When a message is posted to the mailbox (or the timeout period expires) and the task that called `OSMboxPend()` is again the highest priority task then `OSSched()` returns. `OSMboxPend()` checks to see if a message was placed in the task's TCB by `OSMboxPost()` L6.15(6). If this is the case, the call is successful and the message is returned to the caller. Note that we again need to clear the mailbox's content by placing a `NULL`-pointer in `.OSEventPtr`.

A timeout is detected by looking at the `.OSTCBStat` field in the task's TCB to see if the `OS_STAT_MBOX` bit is still set. A timeout occurred when the bit is set L6.15(7). The task is removed from the mailbox's wait list by calling `OSEventTO()` L6.15(8). Note that the returned pointer is set to `NULL` L6.15(9) because there was no message. If the status flag in the task's TCB doesn't have the `OS_STAT_MBOX` bit set then a message must have been sent. The task that called `OSMboxPend()` will thus receive the pointer to the message L6.15(10). Also, the link to the ECB is removed L6.15(11).

```
void *OSMboxPend (OS_EVENT *pevent, INT16U timeout, INT8U *err)
{
    void *msg;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_MBOX) {                (1)
        OS_EXIT_CRITICAL();
        *err = OS_ERR_EVENT_TYPE;
        return ((void *)0);
    }
    msg = pevent->OSEventPtr;
    if (msg != (void *)0) {                                          (2)
        pevent->OSEventPtr = (void *)0;                             (3)
        OS_EXIT_CRITICAL();
        *err = OS_NO_ERR;
    } else if (OSIntNesting > 0) {                                    (4)
        OS_EXIT_CRITICAL();
        *err = OS_ERR_PEND_ISR;
    } else {
        OSTCBCur->OSTCBStat |= OS_STAT_MBOX;                        (5)
        OSTCBCur->OSTCBDly = timeout;
        OSEventTaskWait(pevent);
        OS_EXIT_CRITICAL();
        OSSched();
        OS_ENTER_CRITICAL();
        if ((msg = OSTCBCur->OSTCBMsg) != (void *)0) {              (6)
            OSTCBCur->OSTCBMsg = (void *)0;
            OSTCBCur->OSTCBStat = OS_STAT_RDY;
            OSTCBCur->OSTCBEventPtr = (OS_EVENT *)0;
            OS_EXIT_CRITICAL();
        }
    }
}
```

```

        *err                = OS_NO_ERR;
    } else if (OSTCBCur->OSTCBStat & OS_STAT_MBOX) {           (7)
        OSEventTO(pevent);                                     (8)
        OS_EXIT_CRITICAL();
        msg                = (void *)0;                       (9)
        *err                = OS_TIMEOUT;
    } else {
        msg                = pevent->OSEventPtr;              (10)
        pevent->OSEventPtr  = (void *)0;
        OSTCBCur->OSTCBEventPtr = (OS_EVENT *)0;              (11)
        OS_EXIT_CRITICAL();
        *err                = OS_NO_ERR;
    }
}
return (msg);
}

```

**Listing 6.15, Waiting for a message to arrive at a mailbox.**

### ***6.06.03 Sending a message to a mailbox, OSMboxPost()***

The code to deposit a message in a mailbox is shown in listing 6.16. After making sure that the ECB is used as a mailbox L6.16(1), **OSMboxPost()** checks to see if any task is waiting for a message to arrive at the mailbox L6.16(2). There are tasks waiting when the **OSEventGrp** field in the ECB contains a non-zero value. The highest priority task waiting for the message will be removed from the wait list by **OSEventTaskRdy()** (see section 6.02, *Making a task ready, OSEventTaskRdy()*) L6.16(3), and this task will be made ready-to-run. **OSSched()** is then called to see if the task made ready is now the highest priority task ready-to-run. If it is, a context switch will result (only if **OSMboxPost()** is called from a task) and the readied task will be executed. If the readied task is not the highest priority task then **OSSched()** will return and the task that called **OSMboxPost()** will continue execution. If there were no tasks waiting for a message to arrive at the mailbox, then the pointer to the message is saved in the mailbox L6.16(6), assuming there isn't already a non-NULL pointer L6.16(5). Storing the pointer in the mailbox allows the next task to call **OSMboxPend()** to immediately get the message.

You should note that a context switch does not occur if **OSMboxPost()** is called by an ISR because context switching from an ISR can only occur when **OSIntExit()** is called at the completion of the ISR, and from the last nested ISR (see section 3.09, *Interrupts under  $\mu$ C/OS-II*).

```

INT8U OSMboxPost (OS_EVENT *pevent, void *msg)
{
    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_MBOX) {           (1)
        OS_EXIT_CRITICAL();
        return (OS_ERR_EVENT_TYPE);
    }
    if (pevent->OSEventGrp) {                                    (2)
        OSEventTaskRdy(pevent, msg, OS_STAT_MBOX);             (3)
        OS_EXIT_CRITICAL();
        OSSched();                                              (4)
        return (OS_NO_ERR);
    } else {
        if (pevent->OSEventPtr != (void *)0) {                  (5)
            OS_EXIT_CRITICAL();
            return (OS_MBOX_FULL);
        } else {
            pevent->OSEventPtr = msg;                             (6)
            OS_EXIT_CRITICAL();
            return (OS_NO_ERR);
        }
    }
}

```

```
}
}
```

### Listing 6.16, Depositing a message in a mailbox.

#### 6.06.04 Getting a message without waiting, *OSMboxAccept()*

It is possible to obtain a message from a mailbox without putting a task to sleep if the mailbox is empty. This is accomplished by calling **OSMboxAccept()** and the code for this function is shown in listing 6.17. **OSMboxAccept()** starts by checking that the ECB being pointed to by **pevent** has been created by **OSMboxCreate()** L6.17(1). **OSMboxAccept()** then gets the current contents of the mailbox L6.17(2) in order to determine whether a message is available (i.e. non-**NULL** pointer) L6.17(3). If a message is available, the mailbox is emptied L6.17(4). Finally, the original contents of the mailbox is returned to the caller L6.17(5). The code that called **OSMboxAccept()** will need to examine the returned value. If **OSMboxAccept()** returns a **NULL** pointer then a message was not available. A non-**NULL** pointer indicates that a message was deposited in the mailbox. An ISR should use **OSMboxAccept()** instead of **OSMboxPend()**.

You can use **OSMboxAccept()** to ‘flush’ the contents of a mailbox.

```
void *OSMboxAccept (OS_EVENT *pevent)
{
    void *msg;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_MBOX) {           (1)
        OS_EXIT_CRITICAL();
        return ((void *)0);
    }
    msg = pevent->OSEventPtr;                                   (2)
    if (msg != (void *)0) {                                     (3)
        pevent->OSEventPtr = (void *)0;                         (4)
    }
    OS_EXIT_CRITICAL();
    return (msg);                                              (5)
}
```

### Listing 6.17, Getting a message without waiting.

#### 6.06.05 Obtaining the status of a mailbox, *OSMboxQuery()*

**OSMboxQuery()** allows your application to take a ‘snapshot’ of an ECB used for a message mailbox. The code for this function is shown in listing 6.18. **OSMboxQuery()** is passed two arguments: **pevent** contains a pointer to the message mailbox which is returned by **OSMboxCreate()** when the mailbox is created and, **pdata** which is a pointer to a data structure (**OS\_MBOX\_DATA**, see **uCOS\_II.H**) that will hold information about the message mailbox. Your application will thus need to allocate a variable of type **OS\_MBOX\_DATA** that will be used to receive the information about the desired mailbox. I decided to use a new data structure because the caller should only be concerned with mailbox specific data as opposed to the more generic **OS\_EVENT** data structure which contain two additional fields (i.e. **.OSEventCnt** and **.OSEventType**). **OS\_MBOX\_DATA** contains the current contents of the message (i.e. **.OSMsg**) and the list of tasks waiting for a message to arrive (**.OSEventTbl[]** and **.OSEventGrp**).

As always, our function checks that **pevent** points to an ECB containing a mailbox L6.18(1). **OSMboxQuery()** then copies the wait list L6.18(2) followed by the current message L6.18(3) from the **OS\_EVENT** structure to the **OS\_MBOX\_DATA** structure.

```

INT8U OSMboxQuery (OS_EVENT *pevent, OS_MBOX_DATA *pdata)
{
    INT8U i;
    INT8U *psrc;
    INT8U *pdest;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_MBOX) {           (1)
        OS_EXIT_CRITICAL();
        return (OS_ERR_EVENT_TYPE);
    }
    pdata->OSEventGrp = pevent->OSEventGrp;                     (2)
    psrc               = &pevent->OSEventTbl[0];
    pdest              = &pdata->OSEventTbl[0];
    for (i = 0; i < OS_EVENT_TBL_SIZE; i++) {
        *pdest++ = *psrc++;
    }
    pdata->OSMsg        = pevent->OSEventPtr;                     (3)
    OS_EXIT_CRITICAL();
    return (OS_NO_ERR);
}

```

**Listing 6.18, Obtaining the status of a mailbox.**

### ***6.06.06 Using a mailbox as a binary semaphore***

A message mailbox can be used as a binary semaphore by initializing the mailbox with a non-**NULL** pointer ((**void \*1**) works well). A task requesting the ‘semaphore’ would call **OSMboxPend()** and would release the ‘semaphore’ by calling **OSMboxPost()**. Listing 6.19 shows how this works. You would use this technique to conserve code space if your application only needed binary semaphores and mailboxes. In this case, you could set **OS\_SEM\_EN** to 0 and only use mailboxes instead of both mailboxes and semaphores.

```

OS_EVENT *MboxSem;

void Task1 (void *pdata)
{
    INT8U err;

    for (;;) {
        OSMboxPend(MboxSem, 0, &err);    /* Obtain access to resource(s) */
        .
        .    /* Task has semaphore, access resource(s) */
        .
        OSMboxPost(MboxSem, (void *)1); /* Release access to resource(s) */
    }
}

```

**Listing 6.19, Using a mailbox as a binary semaphore.**

### 6.06.07 Using a mailbox instead of OSTimeDly()

The timeout feature of a mailbox can be used to simulate a call to `OSTimeDly()`. As shown in listing 6.20, `Task1()` resumes execution after the time period expired if no message is received within the specified `TIMEOUT` period. This is basically identical to `OSTimeDly(TIMEOUT)`. However, the task can be resumed by `Task2()` when `Task2()` post a 'dummy' message to the mailbox before the timeout expires. This is the same as calling `OSTimeDlyResume()` had `Task1()` called `OSTimeDly()`. You should note that the returned message is ignored because we are not actually looking to get a message from another task or an ISR.

```
OS_EVENT *MboxTimeDly;

void Task1 (void *pdata)
{
    INT8U err;

    for (;;) {
        OSMboxPend(MboxTimeDly, TIMEOUT, &err);    /* Delay task          */
        .                                           /* Code executed after time delay */
        .
    }
}

void Task2 (void *pdata)
{
    INT8U err;

    for (;;) {
        OSMboxPost(MboxTimeDly, (void *)1);        /* Cancel delay for Task1 */
        .
        .
    }
}
```

**Listing 6.20, Using a mailbox as a time delay.**

## 6.07 Message Queues

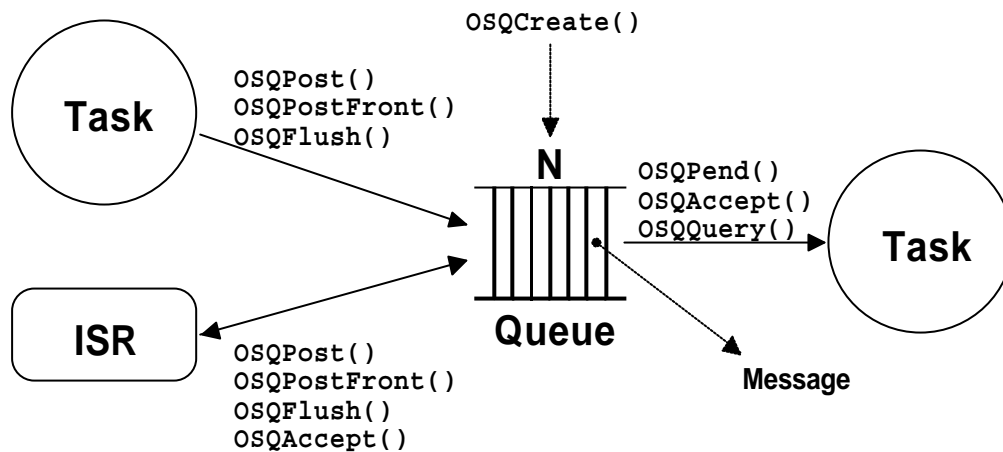
A message queue (or simply a queue) is a  $\mu$ C/OS-II object that allows a task or an ISR to send pointer size variables to another task. Each pointer would typically be initialized to point to some application specific data structure containing a 'message'. To enable  $\mu$ C/OS-II's message queue services, you must set the configuration constant `OS_Q_EN` to 1 (see file `OS_CFG.H`) and determine how many message queues  $\mu$ C/OS-II will need to support by setting the configuration constant `OS_MAX_QS`, also found in `OS_CFG.H`.

A queue needs to be created before it can be used. Creating a queue is accomplished by calling `OSQCreate()` (see next section) and specifying the number of entries (i.e. pointers) that a queue can hold.

$\mu$ C/OS-II provides seven services to access message queues: `OSQCreate()`, `OSQPend()`, `OSQPost()`, `OSQPostFront()`, `OSQAccept()`, `OSQFlush()` and `OSQQuery()`. Figure 6-7 shows a flow diagram to illustrate the relationship between tasks, ISRs and a message queue. Note that the symbology used to represent a queue looks like a mailbox with multiple entries. In fact, you can think of a queue as an array of mailboxes except that there is only one wait list associated with the queue. Again, what the pointers point to is application specific. 'N

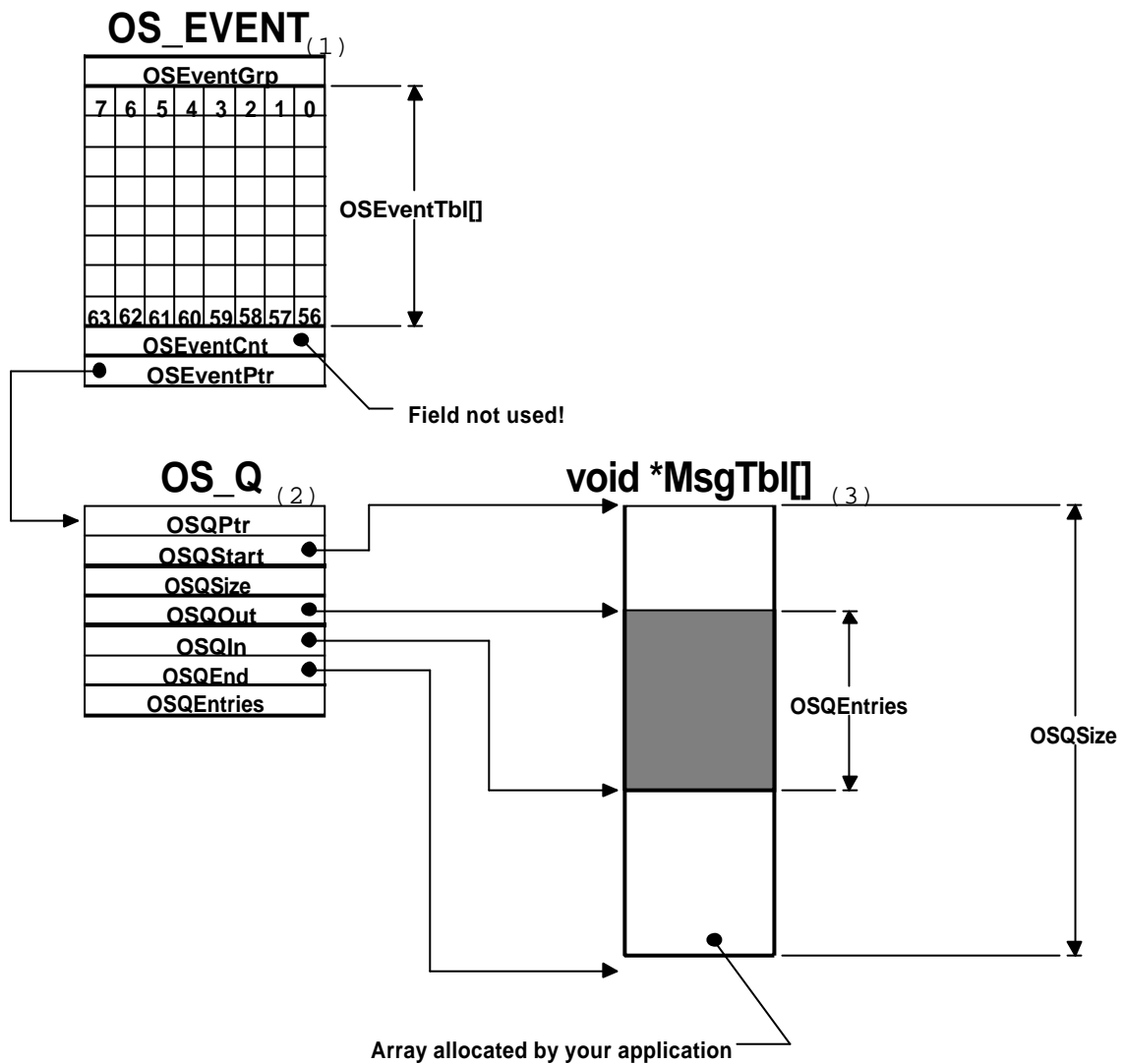


represents the number of entries that the queue holds. The queue is full when your application has called `OSQPost()` (or `OSQPostFront()`) 'N' times before your application has called `OSQPend()` or `OSQAccept()`. As you can see from figure 6-7, a task or an ISR can call `OSQPost()`, `OSQPostFront()`, `OSQFlush()` or `OSQAccept()`. However, only tasks are allowed to call `OSQPend()` and `OSQQuery()`.



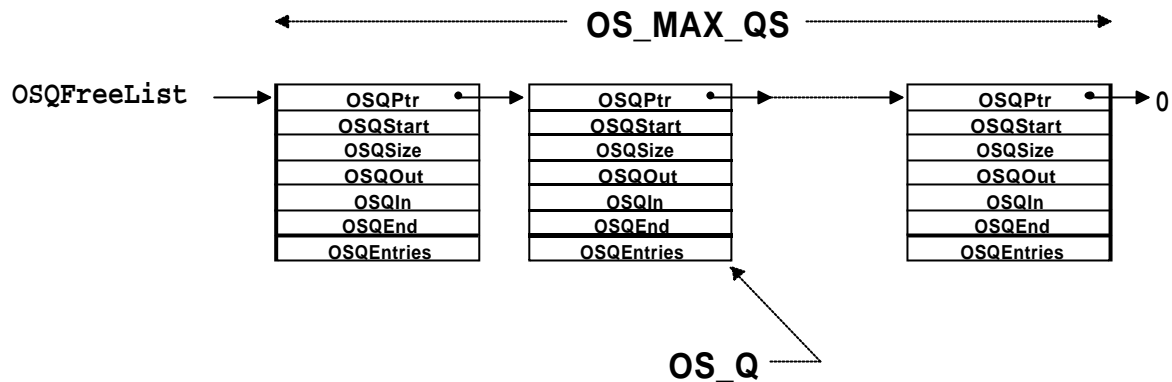
**Figure 6-7, Relationship between tasks, ISRs and a message queue.**

Figure 6-8 shows the different data structures needed to implement a message queue. An ECB is required because we need a wait list F6-8(1) and using an ECB allows us to use some of the same code as we used with semaphores and mailboxes. When a message queue is created, a queue control block (i.e. an `OS_Q`, see `OS_Q.C`) is allocated and linked to the ECB using the `.OSEventPtr` field in `OS_EVENT`, F6-8(2). Before you create a queue, however, you need to allocate an array of pointer F6-8(3) which contains the desired number of queue entries. In other words, the number of elements in the array corresponds to the number of entries in the queue. The starting address of the array is passed to `OSQCreate()` as an argument as well as the size (in number of elements) of the array. In fact, you don't actually need to use an array as long as the memory occupies contiguous locations.



**Figure 6-8, Data structures used in a message queue.**

The configuration constant `OS_MAX_QS` in `OS_CFG.H` specifies how many queues you are allowed to have in your application and MUST be set to at least 2. When  $\mu$  C/OS-II is initialized, a list of free queue control blocks is created as shown in figure 6-9.



**Figure 6-9, List of free queue control blocks.**

A queue control block is a data structure that is used to maintain information about the queue and it contains the fields described below. Note that the fields are preceded with a dot to show that they are members of a structure as opposed to simple variables.

**.OSQPtr** is used to link queue control blocks in the list of free queue control blocks. Once the queue is allocated, this field is not used.

**.OSQStart** contains a pointer to the start of the message queue storage area. Your application must declare this storage area before creating the queue.

**.OSQEnd** is a pointer to one location past the end of the queue. This pointer is used to make the queue a circular buffer.

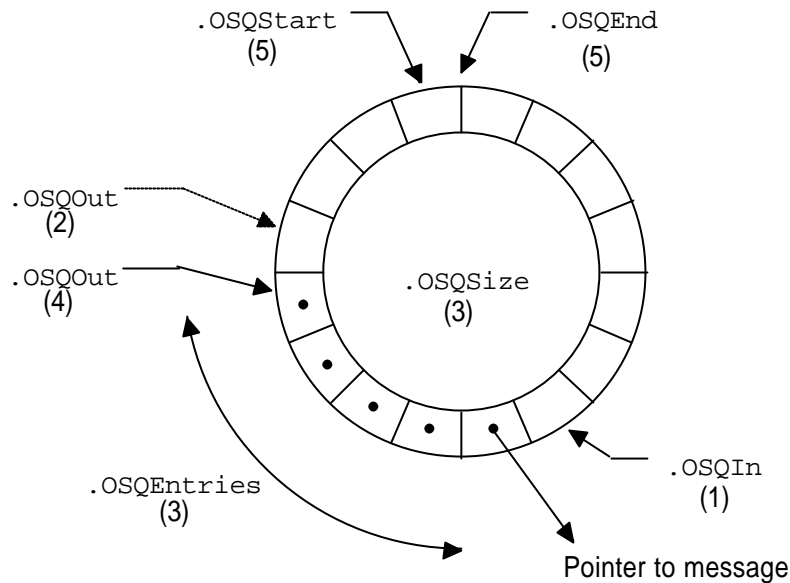
**.OSQIn** is a pointer to the location in the queue where the next message will be inserted. **.OSQIn** is adjusted back to the beginning of the message storage area when **.OSQIn** equals **.OSQEnd**.

**.OSQOut** is a pointer to the next message to be extracted from the queue. **.OSQOut** is adjusted back to the beginning of the message storage area when **.OSQOut** equals **.OSQEnd**. **.OSQOut** is also used to insert a message (see **OSQPostFront()**).

**.OSQSize** contains the size of the message storage area. The size of the queue is determined by your application when the queue is created. Note that  $\mu$  C/OS-II allows the queue to contain up to 65535 entries.

**.OSQEntries** contains the current number of entries in the message queue. The queue is empty when **.OSQEntries** is zero and full when it equals **.OSQSize**. The message queue is empty when the queue is created.

A message queue is basically a circular buffer as shown in figure 6-10. Each entry contains a pointer. The pointer to the next message is deposited at the entry pointed to by **.OSQIn** F6-10(1) unless the queue is full (i.e. **.OSQEntries == .OSQSize**) F6-10(3). Depositing the pointer at **.OSQIn** implements a FIFO (First-In-First-Out) queue. We can implement a LIFO (Last-In-First-Out) queue by pointing to the entry preceding **.OSQOut** F6-10(2) and depositing the pointer at that location. The pointer is also considered full when **.OSQEntries == .OSQSize**. Message pointers are always extracted from the entry pointed to by **.OSQOut**. The pointers **.OSQStart** and **.OSQEnd** are simply markers used to establish the beginning and end of the array so that **.OSQIn** and **.OSQOut** can wrap around to implement this circular motion.



**Figure 6-10, Message queue is a circular buffer of pointers.**

### 6.07.01 Creating a Queue, *OSQCreate()*

The code to create a message queue is shown in listing 6.21. **OSQCreate()** requires that you allocate an array of pointers that will hold the message. The array **MUST** be declared as an array of pointers to **void**.

**OSQCreate()** starts by obtaining an ECB from the free list of ECBs (see figure 6-3) L6.21(1). The linked list of free ECBs is adjusted to point to the next free ECB L6.21(2). Other **OSQ???**( ) function calls will check this field to make sure that the ECB is of the proper type. This prevents you from calling **OSQPost()** on an ECB that was created for use as a semaphore (see section 6.05). Next, **OSQCreate()** obtains a queue control block from the free list L6-21(3). **OSQCreate()** initializes the queue control block L6-21(4) (if one was available), sets the ECB type to **OS\_EVENT\_TYPE\_Q** L6.21(5) and makes **.OSEventPtr** point to the queue control block L6.21(6). The wait list is initialized by calling **OSEventWaitListInit()** (see section 6.01, *Initializing an ECB, OSEventWaitListInit()*) L6.9(7). Because the queue is being initialized, there are no tasks waiting. Finally, **OSQCreate()** returns a pointer to the allocated ECB L6.21(9). This pointer **MUST** be used in subsequent calls that operate on message queues (**OSQPend()**, **OSQPost()**, **OSQPostFront()**, **OSQFlush()**, **OSQAccept()** and **OSQQuery()**). The pointer is basically used as the queue's handle. Note that if there were no more ECBs, **OSQCreate()** would have returned a **NULL** pointer. If a queue control block was not available, **OSQCreate()** returns the ECB back to the list of free ECBs L6.21(8) (there is no point in wasting the ECB).

You should note that once a message queue has been created, it cannot be deleted. It would be 'dangerous' to delete a message queue object if tasks were waiting for messages from it.

```
OS_EVENT *OSQCreate (void **start, INT16U size)
{
    OS_EVENT *pevent;
    OS_Q      *pq;

    OS_ENTER_CRITICAL();
```

```

    pevent = OSEventFreeList;                                     (1)
    if (OSEventFreeList != (OS_EVENT *)0) {
        OSEventFreeList = (OS_EVENT *)OSEventFreeList->OSEventPtr; (2)
    }
    OS_EXIT_CRITICAL();
    if (pevent != (OS_EVENT *)0) {
        OS_ENTER_CRITICAL();
        pq = OSQFreeList;                                       (3)
        if (OSQFreeList != (OS_Q *)0) {
            OSQFreeList = OSQFreeList->OSQPtr;
        }
        OS_EXIT_CRITICAL();
        if (pq != (OS_Q *)0) {
            pq->OSQStart      = start;                           (4)
            pq->OSQEnd        = &start[size];
            pq->OSQIn         = start;
            pq->OSQOut        = start;
            pq->OSQSize       = size;
            pq->OSQEntries    = 0;
            pevent->OSEventType = OS_EVENT_TYPE_Q;              (5)
            pevent->OSEventPtr = pq;                             (6)
            OSEventWaitListInit(pevent);                         (7)
        } else {
            OS_ENTER_CRITICAL();
            pevent->OSEventPtr = (void *)OSEventFreeList;        (8)
            OSEventFreeList   = pevent;
            OS_EXIT_CRITICAL();
            pevent = (OS_EVENT *)0;
        }
    }
    return (pevent);                                           (9)
}

```

**Listing 6.21, Creating a queue.**

### 6.07.02 Waiting for a message at a Queue, *OSQPend()*

The code to wait for a message to arrive at a queue is shown in listing 6.22. **OSQPend()** verifies that the ECB being pointed to by **pevent** has been created by **OSQCreate()** L6.22(1). A message is available when **.OSQEntries** is greater than 0 L6.22(2). In this case, **OSQPend()** stores the pointer to the message in **msg**, moves the **.OSQOut** pointer so that it points to the next entry in the queue L6.22(3) and, **OSQPend()** decrements the number of entries left in the queue L6.22(4). Because we are implementing a circular buffer, we need to check that **.OSQOut** has not moved past the last valid entry in the array L6.22(5). When this happens, however, **.OSQOut** is adjusted to point back at the beginning of the array L6.22(6). This is the path you are looking for when calling **OSQPend()** and it also happens to be the fastest.

If a message is not available (**.OSEventEntries** is 0) then we check to see if the function was called by an ISR L6.22(7). As with **OSSemPend()** and **OSMboxPend()**, you should not call **OSQPend()** from an ISR because an ISR cannot be made to wait. However, if the message is in fact available, the call to **OSQPend()** would be successful even if called from an ISR!

If a message is not available then the calling task must be suspended until either a message is posted or the specified timeout period expires L6.22(8). When a message is posted to the queue (or the timeout period expired) and the task that called **OSQPend()** is again the highest priority task then **OSSched()** returns L6.22(9). **OSQPend()** then checks to see if a message was placed in the task's TCB by **OSQPost()** L6.22(10). If this is the case, the call is successful, some cleanup work is done to unlink the message queue from the TCB L6.22(11) and the message is returned to the caller L6.22(17).

A timeout is detected by looking at the **.OSTCBStat** field in the task's TCB to see if the **OS\_STAT\_Q** bit is still set. A timeout occurred when the bit is set L6.22(12). The task is removed from the queue's wait list by calling **OSEventTO()** L6.22(13). Note that the returned pointer is set to **NULL** L6.22(14) (no message was available).

If the status flag in the task's TCB doesn't have the **OS\_STAT\_Q** bit set then a message must have been sent and thus, the message is extracted from the queue L6.22(15). Also, the link to the ECB is removed because the task will no longer wait on that message queue L6.22(16).

```
void *OSQPend (OS_EVENT *pevent, INT16U timeout, INT8U *err)
{
    void *msg;
    OS_Q *pq;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_Q) {                (1)
        OS_EXIT_CRITICAL();
        *err = OS_ERR_EVENT_TYPE;
        return ((void *)0);
    }
    pq = pevent->OSEventPtr;
    if (pq->OSQEntries != 0) {                                     (2)
        msg = *pq->OSQOut++;                                       (3)
        pq->OSQEntries--;                                           (4)
        if (pq->OSQOut == pq->OSQEnd) {                             (5)
            pq->OSQOut = pq->OSQStart;                               (6)
        }
        OS_EXIT_CRITICAL();
        *err = OS_NO_ERR;
    } else if (OSIntNesting > 0) {                                (7)
        OS_EXIT_CRITICAL();
        *err = OS_ERR_PEND_ISR;
    } else {
        OSTCBCur->OSTCBStat |= OS_STAT_Q;                         (8)
        OSTCBCur->OSTCBDly = timeout;
        OSEventTaskWait(pevent);
        OS_EXIT_CRITICAL();
        OSSched();                                                 (9)
        OS_ENTER_CRITICAL();
        if ((msg = OSTCBCur->OSTCBMsg) != (void *)0) {            (10)
            OSTCBCur->OSTCBMsg = (void *)0;
            OSTCBCur->OSTCBStat = OS_STAT_RDY;
            OSTCBCur->OSTCBEventPtr = (OS_EVENT *)0;              (11)
            OS_EXIT_CRITICAL();
            *err = OS_NO_ERR;
        } else if (OSTCBCur->OSTCBStat & OS_STAT_Q) {             (12)
            OSEventTO(pevent);                                     (13)
            OS_EXIT_CRITICAL();
            msg = (void *)0;                                       (14)
            *err = OS_TIMEOUT;
        } else {
            msg = *pq->OSQOut++;                                     (15)
            pq->OSQEntries--;
            if (pq->OSQOut == pq->OSQEnd) {
                pq->OSQOut = pq->OSQStart;
            }
            OSTCBCur->OSTCBEventPtr = (OS_EVENT *)0;              (16)
            OS_EXIT_CRITICAL();
            *err = OS_NO_ERR;
        }
    }
}
```

<pre> } return (msg); </pre>	(17)
------------------------------	------

## Listing 6.22, Waiting for a message to arrive at a queue.

### 6.07.03 Sending a message to a queue (FIFO), *OSQPost()*

The code to deposit a message in a queue is shown in listing 6.23. After making sure that the ECB is used as a queue L6.23(1), **OSQPost()** checks to see if any task is waiting for a message to arrive at the queue L6.23(2). There are tasks waiting when the **OSEventGrp** field in the ECB contains a non-zero value. The highest priority task waiting for the message will be removed from the wait list by **OSEventTaskRdy()** (see section 6.02, *Making a task ready*, *OSEventTaskRdy()* L6.23(3), and this task will be made ready-to-run. **OSSched()** is then called to see if the task made ready is now the highest priority task ready-to-run. If it is, a context switch will result (only if **OSQPost()** is called from a task) and the readied task will be executed. If the readied task is not the highest priority task then **OSSched()** will return and the task that called **OSQPost()** will continue execution. If there were no tasks waiting for a message to arrive at the queue, then the pointer to the message is saved in the queue L6.23(5) unless the queue is already full L6.23(4). You should note that if the queue is full, the message will not be inserted in the queue and thus, the message will basically be lost. Storing the pointer to the message in the queue allows the next task that calls **OSQPend()** (on this queue) to immediately get the pointer.

You should note that a context switch does not occur if **OSQPost()** is called by an ISR because context switching from an ISR can only occur when **OSIntExit()** is called at the completion of the ISR, from the last nested ISR (see section 3.09, *Interrupts under  $\mu$  C/OS-II*).

```

INT8U OSQPost (OS_EVENT *pevent, void *msg)
{
    OS_Q    *pq;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_Q) {
        OS_EXIT_CRITICAL();
        return (OS_ERR_EVENT_TYPE);
    }
    if (pevent->OSEventGrp) {
        OSEventTaskRdy(pevent, msg, OS_STAT_Q);
        OS_EXIT_CRITICAL();
        OSSched();
        return (OS_NO_ERR);
    } else {
        pq = pevent->OSEventPtr;
        if (pq->OSQEntries >= pq->OSQSize) {
            OS_EXIT_CRITICAL();
            return (OS_Q_FULL);
        } else {
            *pq->OSQIn++ = msg;
            pq->OSQEntries++;
            if (pq->OSQIn == pq->OSQEnd) {
                pq->OSQIn = pq->OSQStart;
            }
            OS_EXIT_CRITICAL();
        }
        return (OS_NO_ERR);
    }
}

```

### Listing 6.23, Depositing a message in a queue (FIFO).

#### 6.07.04 Sending a message to a queue (LIFO), *OSQPostFront()*

**OSQPostFront()** is basically identical to **OSQPost()** except that **OSQPostFront()** uses **.OSQOut** instead of **.OSQIn** as the pointer to the next entry to insert. The code is shown in listing 6.24. You should note, however, that **.OSQOut** points to an already inserted entry and thus, **.OSQOut** must be made to point to the previous entry. If **.OSQOut** points at the beginning of the array L6.24(1), then a decrement really means positioning **.OSQOut** at the end of the array L6.24(2). However, **.OSQEnd** points to one entry past the array and thus **.OSQOut** needs to be adjusted to be within range L6.24(3). **OSQPostFront()** implements a LIFO queue because the next message extracted by **OSQPend()** will be the last message inserted by **OSQPostFront()**.

```
INT8U OSQPostFront (OS_EVENT *pevent, void *msg)
{
    OS_Q    *pq;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_Q) {
        OS_EXIT_CRITICAL();
        return (OS_ERR_EVENT_TYPE);
    }
    if (pevent->OSEventGrp) {
        OSEventTaskRdy(pevent, msg, OS_STAT_Q);
        OS_EXIT_CRITICAL();
        OSSched();
        return (OS_NO_ERR);
    } else {
        pq = pevent->OSEventPtr;
        if (pq->OSQEntries >= pq->OSQSize) {
            OS_EXIT_CRITICAL();
            return (OS_Q_FULL);
        } else {
            if (pq->OSQOut == pq->OSQStart) {           (1)
                pq->OSQOut = pq->OSQEnd;               (2)
            }
            pq->OSQOut--;                               (3)
            *pq->OSQOut = msg;
            pq->OSQEntries++;
            OS_EXIT_CRITICAL();
        }
        return (OS_NO_ERR);
    }
}
```

### Listing 6.24, Depositing a message in a queue (LIFO).

#### 6.07.05 Getting a message without waiting, *OSQAccept()*

It is possible to obtain a message from a queue without putting a task to sleep if the queue is empty. This is accomplished by calling **OSQAccept()** and the code for this function is shown in listing 6.25. **OSQAccept()** starts by checking that the ECB being pointed to by **pevent** has been created by **OSQCreate()** L6.25(1). **OSQAccept()** then checks to see if there are any entries in the queue L6.25(2). If the queue contains at least one message, the next pointer is extracted from the queue L6.25(3). The code that calls **OSQAccept()** will need to examine the returned value. If **OSQAccept()** returns a **NULL** pointer then a message was not available L6.25(4). A



non-NULL pointer indicates that a message pointer was available. An ISR should use **OSQAccept()** instead of **OSQPend()**. If an entry was available, **OSQAccept()** extracts the entry from the queue.

```
void *OSQAccept (OS_EVENT *pevent)
{
    void *msg;
    OS_Q *pq;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_Q) {           (1)
        OS_EXIT_CRITICAL();
        return ((void *)0);
    }
    pq = pevent->OSEventPtr;
    if (pq->OSQEntries != 0) {                                (2)
        msg = *pq->OSQOut++;                                  (3)
        pq->OSQEntries--;
        if (pq->OSQOut == pq->OSQEnd) {
            pq->OSQOut = pq->OSQStart;
        }
    } else {
        msg = (void *)0;                                     (4)
    }
    OS_EXIT_CRITICAL();
    return (msg);
}
```

**Listing 6.25, Getting a message without waiting.**

### ***6.07.06 Flushing a queue, OSQFlush()***

**OSQFlush()** allows your application to remove all the messages posted to a queue and basically, start with a fresh queue. The code for this function is shown in listing 6.26. As usual,  $\mu$  C/OS-II checks to ensure that **pevent** is pointing to a message queue L6.26(1). The IN and OUT pointers are then reset to the beginning of the array and the number of entries is cleared L6.26(2). I decided to not check to see if there were any tasks pending on the queue because this would be irrelevant anyway. In other words, if tasks were waiting on the queue then **.OSQEntries** would already have been set to 0. The only difference is that **.OSQIn** and **.OSQOut** may have been pointing elsewhere in the array.

```
INT8U OSQFlush (OS_EVENT *pevent)
{
    OS_Q *pq;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_Q) {           (1)
        OS_EXIT_CRITICAL();
        return (OS_ERR_EVENT_TYPE);
    }
    pq = pevent->OSEventPtr;
    pq->OSQIn = pq->OSQStart;                                (2)
    pq->OSQOut = pq->OSQStart;
    pq->OSQEntries = 0;
    OS_EXIT_CRITICAL();
    return (OS_NO_ERR);
}
```

## Listing 6.26, Flushing the contents of a queue.

### 6.07.07 Obtaining the status of a queue, *OSQQuery()*

**OSQQuery()** allows your application to take a ‘snapshot’ of the contents of a message queue. The code for this function is shown in listing 6.27. **OSQQuery()** is passed two arguments: **pevent** contains a pointer to the message queue which is returned by **OSQCreate()** when the queue is created and, **pdata** which is a pointer to a data structure (**OS\_Q\_DATA**, see **uCOS\_II.H**) that will hold information about the message queue. Your application will thus need to allocate a variable of type **OS\_Q\_DATA** that will be used to receive the information about the desired queue. **OS\_Q\_DATA** contains the following fields:

**.OSMsg** contains the contents pointed to by **.OSQOut** if there are entries in the queue. If the queue is empty, **.OSMsg** contains a **NULL**-pointer.

**.OSNMsgs** contains the number of messages in the queue (i.e. a copy of **.OSQEntries**).

**.OSQSize** contains the size of the queue (in number of entries).

**.OSEventTbl[]** and **.OSEventGrp** contains a snapshot of the message queue wait list. The caller to **OSQQuery()** can thus determine how many tasks are waiting for the queue.

As always, our function checks that **pevent** points to an ECB containing a queue L6.27(1). **OSQQuery()** then copies the wait list L6.27(2). If the queue contains any entries L6.27(3), the next message pointer to be extracted from the queue is copied into the **OS\_Q\_DATA** structure L6.27(4). If the queue is empty, then a **NULL**-pointer is placed in **OS\_Q\_DATA** L6.27(5). Finally, we copy the number of entries and the size of the message queue L6.27(6).

```
INT8U OSQQuery (OS_EVENT *pevent, OS_Q_DATA *pdata)
{
    OS_Q    *pq;
    INT8U    i;
    INT8U    *psrc;
    INT8U    *pdest;

    OS_ENTER_CRITICAL();
    if (pevent->OSEventType != OS_EVENT_TYPE_Q) {                (1)
        OS_EXIT_CRITICAL();
        return (OS_ERR_EVENT_TYPE);
    }
    pdata->OSEventGrp = pevent->OSEventGrp;                      (2)
    psrc               = &pevent->OSEventTbl[0];
    pdest              = &pdata->OSEventTbl[0];
    for (i = 0; i < OS_EVENT_TBL_SIZE; i++) {
        *pdest++ = *psrc++;
    }
    pq = (OS_Q *)pevent->OSEventPtr;
    if (pq->OSQEntries > 0) {                                     (3)
        pdata->OSMsg = pq->OSQOut;                               (4)
    } else {
        pdata->OSMsg = (void *)0;                               (5)
    }
    pdata->OSNMsgs = pq->OSQEntries;                             (6)
    pdata->OSQSize = pq->OSQSize;
    OS_EXIT_CRITICAL();
    return (OS_NO_ERR);
}
```

## Listing 6.27, Obtaining the status of a queue.

### 6.07.08 Using a message queue when reading analog inputs

It is often useful in control applications to read analog inputs at a regular interval. To accomplish this, you can create a task and call `OSTimeDly()` (see section 5.00, `OSTimeDly()`) and specify the desired sampling period. As shown in figure 6-11, you could use a message queue instead and have your task pend on the queue with a timeout. The timeout corresponds to the desired sampling period. If no other task sends a message to the queue, the task will be resumed after the specified timeout which basically emulates the `OSTimeDly()` function.

You are probably wondering why I decided to use a queue when `OSTimeDly()` does the trick just fine. By adding a queue, you can have other tasks abort the wait by sending a message thus forcing an immediate conversion. If you add some intelligence to your messages, you can tell the ADC task to convert a specific channel, tell the task to increase the sampling rate, and more. In other words, you can say to the task: “Can you convert analog input #3 for me now?”. After servicing the message, the task would initiate the pend on the queue which would restart the scanning process.

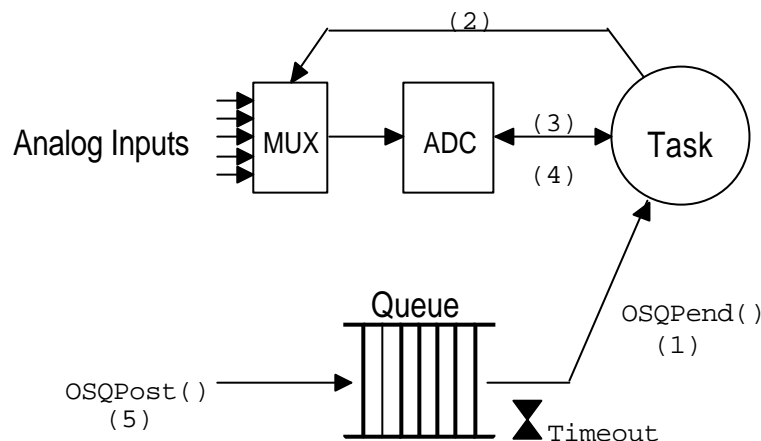


Figure 6-11, Reading analog inputs.

### 6.07.09 Using a queue as a counting semaphore

A message queue can be used as a counting semaphore by initializing and loading a queue with as many non-NULL pointer (`void *1`) works well) as there are resources available. A task requesting the ‘semaphore’ would call `OSQPend()` and would release the ‘semaphore’ by calling `OSQPost()`. Listing 6.28 shows how this works. You would use this technique to conserve code space if your application only needed counting semaphores and message queues (you would then have no need for the semaphore services). In this case, you could set `OS_SEM_EN` to 0 and only use queues instead of both queues and semaphores. You should note that this technique consumes a pointer size variable for each resource that the semaphore is guarding as well as requiring a queue control block. In other words, you will be sacrificing RAM space in order to save code space. Also, message queues services are slower than semaphore services. This technique would be very inefficient if your counting semaphore (in this case a queue) is guarding a large amount of resources (you would require a large array of pointers).

```
OS_EVENT *QSem;
void *QMsgTbl[N_RESOURCES]
```

```

void main (void)
{
    OSInit();
    .
    .
    QSem = OSQCreate(&QMsgTbl[0], N_RESOURCES);
    for (i = 0; i < N_RESOURCES; i++) {
        OSQPost(QSem, (void *)1);
    }
    .
    .
    OSTaskCreate(Task1, ..., ..., ..);
    .
    .
    OSStart();
}

void Task1 (void *pdata)
{
    INT8U err;

    for (;;) {
        OSQPend(&QSem, 0, &err);          /* Obtain access to resource(s) */
        .
        .      /* Task has semaphore, access resource(s) */
        .
        OSMQPost(QSem, (void *)1);        /* Release access to resource(s) */
    }
}

```

**Listing 6.28, Using a queue as a counting semaphore.**

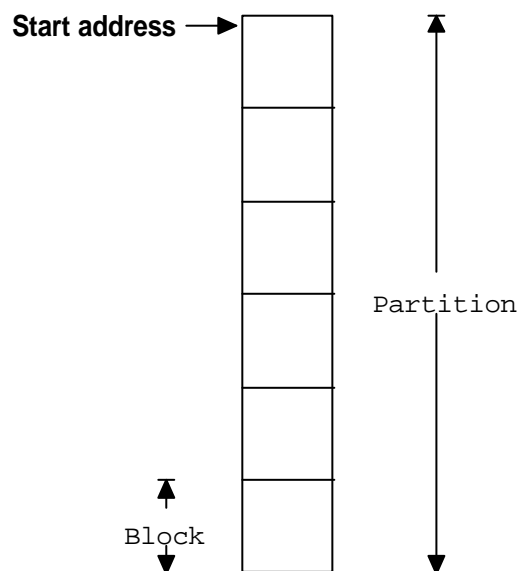
## Chapter 7

# Memory Management

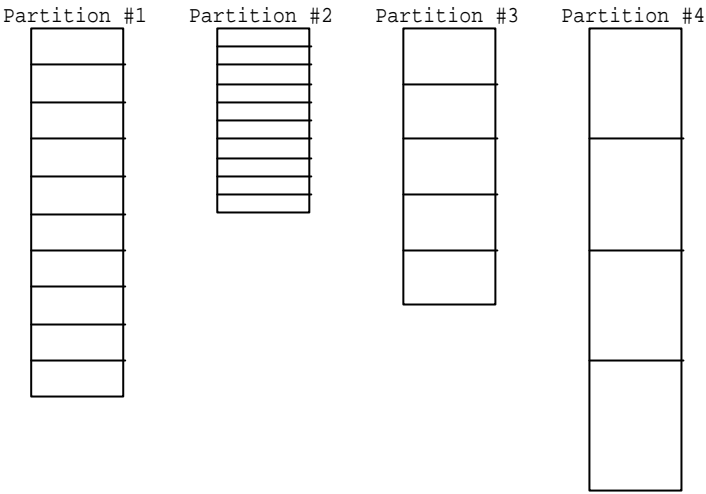
Your application can allocate and free dynamic memory using any ANSI C compiler's **malloc()** and **free()** functions, respectively. However, using **malloc()** and **free()** in an embedded real-time system is dangerous because eventually, you may not be able to obtain a single contiguous memory area because of *fragmentation*. Fragmentation is the development of a large number of separate free areas (i.e. the total free memory is fragmented into small pieces). I discussed the problem of fragmentation in section 4.02 when I indicated that task stacks could be allocated using **malloc()**. Execution time of **malloc()** and **free()** are also generally non-deterministic because of the algorithms used to locate a contiguous block of free memory.

$\mu$ C/OS-II provides an alternative to **malloc()** and **free()** by allowing your application to obtain fixed-sized *memory blocks* from a *partition* made of a contiguous memory area as illustrated in Figure 7-1. All memory blocks are the same size and the partition contains an integral number of blocks. Allocation and de-allocation of these memory blocks is done in constant time and is deterministic.

As shown in Figure 7-2, more than one memory partition can exist and thus, your application can obtain memory blocks of different sizes. A specific memory block must, however, always be returned to the partition from which it came from. This type of memory management is not subject to fragmentation.



**Figure 7-1, Memory partition**



**Figure 7-2, Multiple memory partitions.**

## 7.00 Memory Control Blocks

$\mu$  C/OS-II keeps track of memory partitions through the use of a data structure called a *memory control block* as shown in listing 7.1. Each memory partition requires its own memory control block.

```
typedef struct {  
    void    *OSMemAddr;  
    void    *OSMemFreeList;  
    INT32U   OSMemBlkSize;  
    INT32U   OSMemNBlks;  
    INT32U   OSMemNFree;  
} OS_MEM;
```

### Listing 7.1, Memory control block data structure.

**OSMemAddr** is a pointer to the beginning (i.e. base) of the memory partition from which memory blocks will be allocated from. This field is initialized when you create a partition (see section 7.01, *Creating a partition*) and is not used thereafter.

**OSMemFreeList** is a pointer used by  $\mu$  C/OS-II to point to either the next free memory control block or to the next free memory block. The use depends on whether the memory partition has been created or not (see section 7.01).

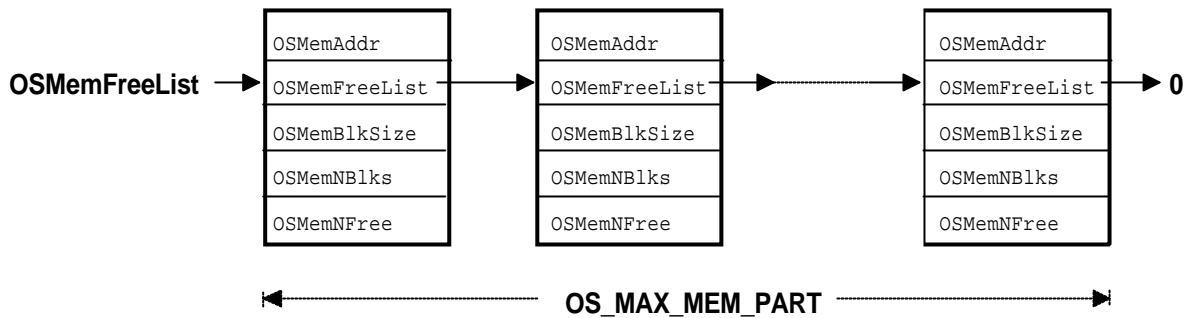
**OSMemBlkSize** determines the size of each memory block in the partition and is a parameter you specify when the memory partition is created (see section 7.01).

**OSMemNBlks** establishes the total number of memory blocks available from the partition. This parameter is specified when the partition is created (see section 7.01).

**OSMemNFree** is used to determine how many memory blocks are available from the partition.

$\mu$  C/OS-II initializes the memory manager if you configure **OS\_MEM\_EN** to **1** in **OS\_CFG.H**. Initialization is done by **OSMemInit()** (which is automatically called by **OSInit()**) and consist of creating a linked list of memory control blocks as shown in figure 7-3. You specify the maximum number of memory partitions with the configuration constant **OS\_MAX\_MEM\_PART** (see **OS\_CFG.H**) which MUST be set to at least 2.

As can be seen, the **OSMemFreeList** field of the control block is used to chain the free control blocks.



**Figure 7-3, List of free memory control blocks.**

### **7.01 Creating a partition, *OSMemCreate()***

Your application must create each partition before they can be used. You create a memory partition by calling **OSMemCreate()**. Listing 7.2 shows how you could create a memory partition containing 100 blocks of 32 bytes each.

```

OS_MEM  *CommTxBuf;
INT8U   CommTxPart[100][32];

void main (void)
{
    INT8U err;

    OSInit();
    .
    .
    CommTxBuf = OSMemCreate(CommTxPart, 100, 32, &err);
    .
    .
    OSStart();
}

```

**Listing 7.2, Creating a memory partition.**

The code to create a memory partition is shown in listing 7.3. **OSMemCreate()** requires four arguments: the beginning address of the memory partition., the number of blocks to be allocated from this partition, the size (in bytes) of each block and, a pointer to a variable that will contain an error code when **OSMemCreate()** returns or a **NULL** pointer if **OSMEMCreate()** fails. Upon success, **OSMemCreate()** returns a pointer to the allocated memory control block. This pointer must be used in subsequent calls to memory management services (see **OSMemGet()**, **OSMemPut()** and **OSMemQuery()** in the next sections).

Each memory partition must contain at least 2 memory blocks L7.3(1). Also, each memory block must be able to hold the size of a pointer because a pointer is used to chain all the memory blocks together L7.3(2). Next, **OSMemCreate()** obtains a memory control block from the list of free memory control blocks L7.3(3). The memory control block will contain run-time information about the memory partition. **OSMemCreate()** will not



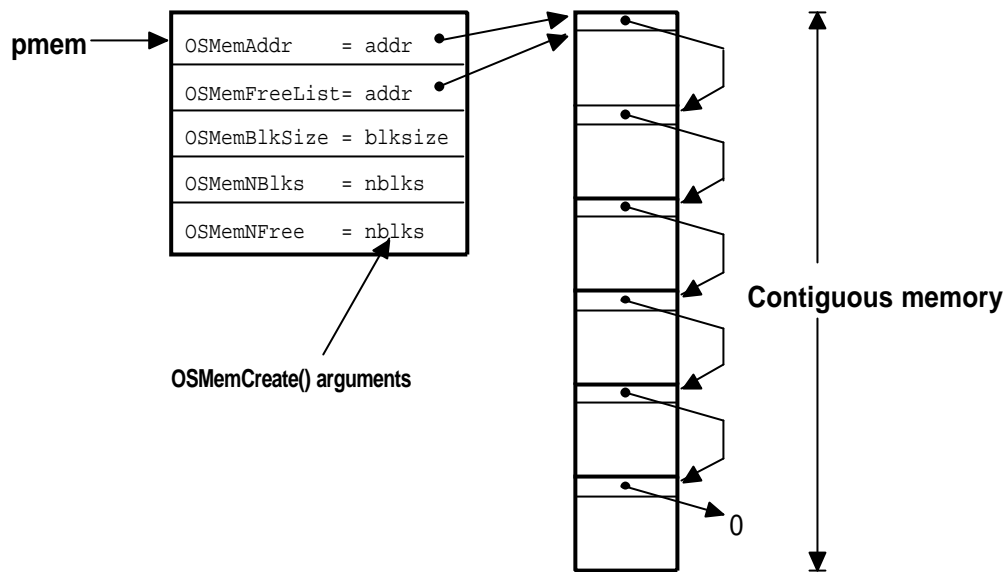
be able to create a memory partition unless a memory control block is available L7.3(4). If a memory control block is available and we satisfied all the previous conditions, the memory blocks within the partition are linked together in a singly linked list L7.3(5). When all the blocks are linked, the memory control block is filled with information about the partition L7.3(6). **OSMemCreate()** returns the pointer to the memory control block so it can be used in subsequent calls to access the memory blocks from this partition L7.3(7).

```
OS_MEM *OSMemCreate (void *addr, INT32U nblks, INT32U blksize, INT8U *err)
{
    OS_MEM  *pmem;
    INT8U    *pblk;
    void     **plink;
    INT32U    i;

    if (nblks < 2) {                                (1)
        *err = OS_MEM_INVALID_BLKS;
        return ((OS_MEM *)0);
    }
    if (blksize < sizeof(void *)) {                  (2)
        *err = OS_MEM_INVALID_SIZE;
        return ((OS_MEM *)0);
    }
    OS_ENTER_CRITICAL();
    pmem = OSMemFreeList;                            (3)
    if (OSMemFreeList != (OS_MEM *)0) {
        OSMemFreeList = (OS_MEM *)OSMemFreeList->OSMemFreeList;
    }
    OS_EXIT_CRITICAL();
    if (pmem == (OS_MEM *)0) {                        (4)
        *err = OS_MEM_INVALID_PART;
        return ((OS_MEM *)0);
    }
    plink = (void **)addr;                            (5)
    pblk = (INT8U *)addr + blksize;
    for (i = 0; i < (nblks - 1); i++) {
        *plink = (void *)pblk;
        plink = (void **)pblk;
        pblk = pblk + blksize;
    }
    *plink = (void *)0;
    OS_ENTER_CRITICAL();
    pmem->OSMemAddr = addr;                            (6)
    pmem->OSMemFreeList = addr;
    pmem->OSMemNFree = nblks;
    pmem->OSMemNBlks = nblks;
    pmem->OSMemBlkSize = blksize;
    OS_EXIT_CRITICAL();
    *err = OS_NO_ERR;
    return (pmem);                                    (7)
}
```

### Listing 7.3, OSMemCreate()

Figure 7-4 shows how the data structures look like when **OSMemCreate()** completes successfully. Note that the memory blocks are shown nicely linked one after the other. At run-time, as you allocate and de-allocate memory blocks, the blocks will most likely not be in this order.



**Figure 7-4, OSMemCreate()**

## 7.02 Obtaining a memory block, OSMemGet()

Your application can get a memory block from one of the created memory partition by calling **OSMemGet ( )**. You simply use the pointer returned by **OSMemCreate ( )** in the call to **OSMemGet ( )** to specify which partition the memory block will come from. Obviously, your application will need to know how big the memory block obtained is so that it doesn't exceed its storage capacity. In other words, you must not use more memory than what is available from the memory block. For example, if a partition contains 32 byte blocks then your application can use up to 32 bytes. When you are done using the block, you must return the block to the proper memory partition (see section 7.03, *Returning a memory block, OSMemPut()*).

Listing 7.4 shows the code for **OSMemGet ( )**. The pointer specifies the partition from which you want to get a memory block from L7.4(1). **OSMemGet ( )** first checks to see if there are free blocks available L7.4(2). If a block is available, it is removed from the free list L7.4(3). The free list is then updated L7.4(4) so that it points to the next free memory block and, the number of blocks is decremented indicating that it has been allocated L7.4(5). The pointer to the allocated block is finally returned to your application L7.4(6).

```
void *OSMemGet (OS_MEM *pmem, INT8U *err)           (1)
{
    void    *pblk;

    OS_ENTER_CRITICAL();
    if (pmem->OSMemNFree > 0) {                     (2)
        pblk = pmem->OSMemFreeList;                 (3)
        pmem->OSMemFreeList = *(void **)pblk;        (4)
        pmem->OSMemNFree--;                           (5)
        OS_EXIT_CRITICAL();
        *err = OS_NO_ERR;
        return (pblk);                               (6)
    } else {
```

```

        OS_EXIT_CRITICAL();
        *err = OS_MEM_NO_FREE_BLKs;
        return ((void *)0);
    }
}

```

### Listing 7.4, OSMemGet()

You should note that you can call this function from an ISR because if a memory block is not available, there is no waiting. The ISR would simply receive a **NULL** pointer if no memory blocks are available.

## 7.03 Returning a memory block, OSMemPut()

When your application is done using a memory block, it must return it to the appropriate partition. This is accomplished by calling **OSMemPut()**. You should note that **OSMemPut()** has no way of knowing whether the memory block returned to the partition belongs to that partition. In other words, if you allocated a memory block from a partition containing blocks of 32 bytes then you should not return this block to a memory partition containing blocks of 120 bytes. The next time an application request a block from the 120 bytes partition, it will actually get 32 'valid' bytes and the remaining 88 bytes may belong to some other task(s). This could certainly make your system crash.

Listing 7.5 shows the code for **OSMemPut()**. You simply pass **OSMemPut()** the address of the memory control block for which the memory block belongs to L7.5(1). We then check to see that the memory partition is not already full L7.5(2). This situation would certainly indicate that something went wrong during the allocation/de-allocation process. If the memory partition can accept another memory block, it is inserted in the linked list of free blocks L7.5(3). Finally, the number of memory blocks in the memory partition is incremented L7.5(4).

```

INT8U OSMemPut (OS_MEM *pmem, void *pblk)                (1)
{
    OS_ENTER_CRITICAL();
    if (pmem->OSMemNFree >= pmem->OSMemNBlks) {           (2)
        OS_EXIT_CRITICAL();
        return (OS_MEM_FULL);
    }
    *(void **)pblk = pmem->OSMemFreeList;                 (3)
    pmem->OSMemFreeList = pblk;
    pmem->OSMemNFree++;                                     (4)
    OS_EXIT_CRITICAL();
    return (OS_NO_ERR);
}

```

### Listing 7.5, OSMemPut()

## 7.04 Obtaining status about memory partition, OSMemQuery()

**OSMemQuery()** is used to obtain information about a memory partition. Specifically, your application can determine how many memory blocks are free, how many memory blocks have been used (i.e. allocated), the size of each memory block (in bytes), etc. This information is placed in a data structure called **OS\_MEM\_DATA** as shown in listing 7.6.

```

typedef struct {
    void *OSAddr;      /* Points to beginning address of the memory partition */
    void *OSFreeList;  /* Points to beginning of the free list of memory blocks */
}

```

```

    INT32U  OSBlkSize;      /* Size (in bytes) of each memory block          */
    INT32U  OSNBlks;       /* Total number of blocks in the partition          */
    INT32U  OSNFree;       /* Number of memory blocks free                    */
    INT32U  OSNUsed;       /* Number of memory blocks used                    */
} OS_MEM_DATA;

```

### Listing 7.6, Data structure used to obtain status from a partition.

The code for **OSMemQuery( )** is shown in listing 7.7. As you can see, all the fields found in **OS\_MEM** are copied to the **OS\_MEM\_DATA** data structure with interrupts disabled L7.7(1). This ensures that the fields will not be altered until they are all copied. You should also notice that computation of the number of blocks used is performed outside of the critical section because it's done using the local copy of the data L7.7(2).

```

INT8U OSMemQuery (OS_MEM *pmem, OS_MEM_DATA *pdata)
{
    OS_ENTER_CRITICAL();
    pdata->OSAddr      = pmem->OSMemAddr;          (1)
    pdata->OSFreeList  = pmem->OSMemFreeList;
    pdata->OSBlkSize   = pmem->OSMemBlkSize;
    pdata->OSNBlks     = pmem->OSMemNBlks;
    pdata->OSNFree     = pmem->OSMemNFree;
    OS_EXIT_CRITICAL();
    pdata->OSNUsed     = pdata->OSNBlks - pdata->OSNFree;  (2)
    return (OS_NO_ERR);
}

```

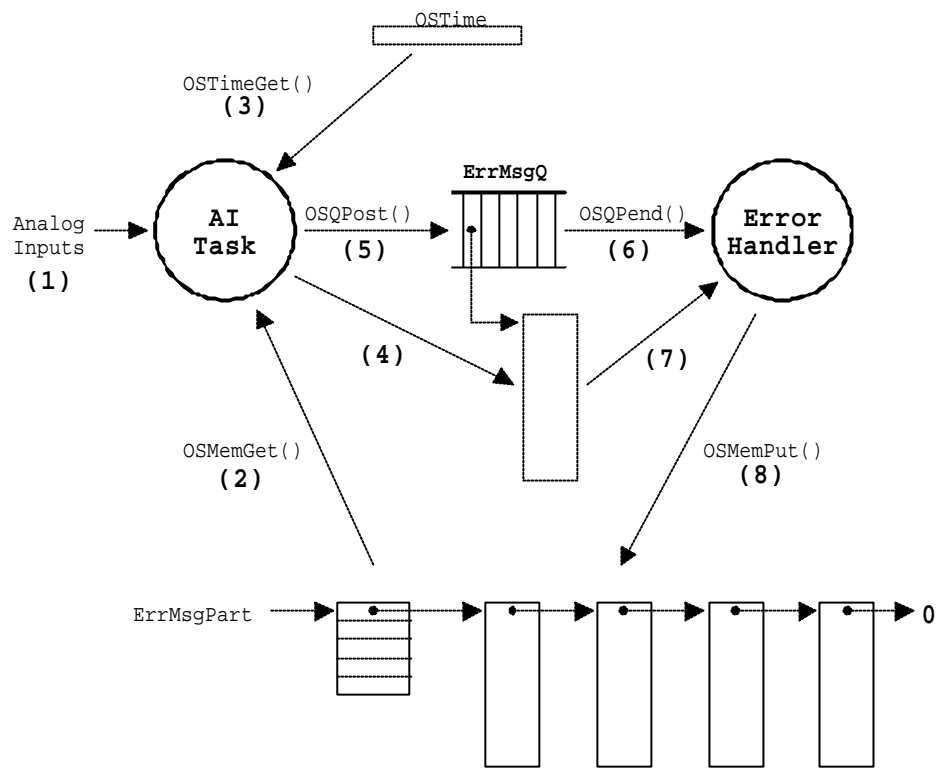
### Listing 7.7, OSMemQuery()

## 7.05 Using memory partitions

Figure 7-5 shows an example of how you can use the dynamic memory allocation feature of  $\mu$  C/OS-II as well as its message passing capability (see chapter 6). Also, refer to listing 7.8 for the pseudo-code of the two tasks shown. The numbers in parenthesis in figure 7-5 correspond to the appropriate action in listing 7.8.

The first task reads and checks the value of analog inputs (pressures, temperatures, voltages, etc.) and sends a message to the second task if any of the analog inputs exceed a threshold. The message sent contains a time stamp, information about which channel had the error, an error code, an indication of the severity of the error and any other information you can think of.

Error handling in this example is centralized. This means that other tasks or even ISRs can post error messages to the error handling task. The error handling task could be responsible for displaying error messages on a monitor (i.e. a display), logging errors to a disk, dispatching other task(s) which would take corrective action(s) based on the error, etc.



**Figure 7-5, Using dynamic memory allocation.**

```

AnalogInputTask()
{
    for (;;) {
        for (all analog inputs to read) {
            Read analog input;                                (1)
            if (analog input exceed threshold) {
                Get memory block;                                (2)
                Get current system time (in clock ticks);        (3)
                Store the following items in the memory block:    (4)
                    System time (i.e. a time stamp);
                    The channel that exceeded the threshold;
                    An error code;
                    The severity of the error;
                    Etc.
                Post the error message to error queue;            (5)
                (A pointer to the memory block containing the data)
            }
        }
        Delay task until it's time to sample analog inputs again;
    }
}

ErrorHandlerTask()
{
    for (;;) {
        Wait for message from error queue;                      (6)
        (Gets a pointer to a memory block containing information
         about the error reported)
        Read the message and take action based on error reported; (7)
        Return the memory block to the memory partition;        (8)
    }
}

```

**Listing 7.8, Scanning analog inputs and reporting errors.**

## ***7.06 Waiting for memory blocks from a partition***

Sometimes it's useful to have a task wait for a memory block in case a partition runs out of blocks.  $\mu$  C/OS-II doesn't support 'pending' on a partitions, but you can support this requirement by adding a counting semaphore (see section 6.05, *Semaphores*) to guard the memory partition. To obtain a memory block, you simply need to obtain a semaphore then call **OSMemGet ( )**. The whole process is shown in listing 7.9.

First we declared our system objects L7.9(1). You should note that I used hard-coded constants for clarity. You would certainly create **#define** constants in a real application. We initialize  $\mu$  C/OS-II by calling **OSInit ( )** L7.9(2). We then create a semaphore with an initial count corresponding to the number of blocks in the partition L7.9(3). We then create the partition L7.9(4) and one of the tasks L7.9(5) that will be accessing the partition. By now, you should be able to figure out what you need to do to add the other tasks. It would obviously not make much sense to use a semaphore if only one task is using memory blocks – there would be no need to ensure mutual exclusion! In fact, it wouldn't even make sense to use partitions unless you intend to share memory blocks with other tasks. Multitasking is then started by calling **OSStart ( )** L7.9(6). When the task gets to execute, it obtains a memory block L7.9(8) only if a semaphore is available L7.9(7). Once the semaphore is available, the memory block is obtained. There is no need to check for returned error code of **OSSemPend ( )** because the only way  $\mu$  C/OS-II will return to this task is if a memory block is released. Also, you don't need the error code for **OSMemGet ( )** for the

same reason – you must have at least one block in the partition in order for the task to resume. When the task is done using a memory block, it simply needs to return it to the partition L7.9(9) and signal the semaphore L7.9(10).

```
OS_EVENT  *SemaphorePtr;                                (1)
OS_MEM    *PartitionPtr;
INT8U     Partition[100][32];
OS_STK    TaskStk[1000];

void main (void)
{
    INT8U err;

    OSInit();                                           (2)
    .
    .
    SemaphorePtr = OSSemCreate(100);                    (3)
    PartitionPtr = OSMemCreate(Partition, 100, 32, &err); (4)
    .
    OSTaskCreate(Task, (void *)0, &TaskStk[999], &err); (5)
    .
    OSStart();                                           (6)
}

void Task (void *pdata)
{
    INT8U err;
    INT8U *pblock;

    for (;;) {
        OSSemPend(SemaphorePtr, 0, &err);              (7)
        pblock = OSMemGet(PartitionPtr, &err);          (8)
        .
        . /* Use the memory block */
        .
        OSMemPut(PartitionPtr, pblock);                  (9)
        OSSemPost(SemaphorePtr);                        (10)
    }
}
```

**Listing 7.9, Waiting for memory blocks from a partition.**

## Chapter 8

# Porting $\mu$ C/OS-II

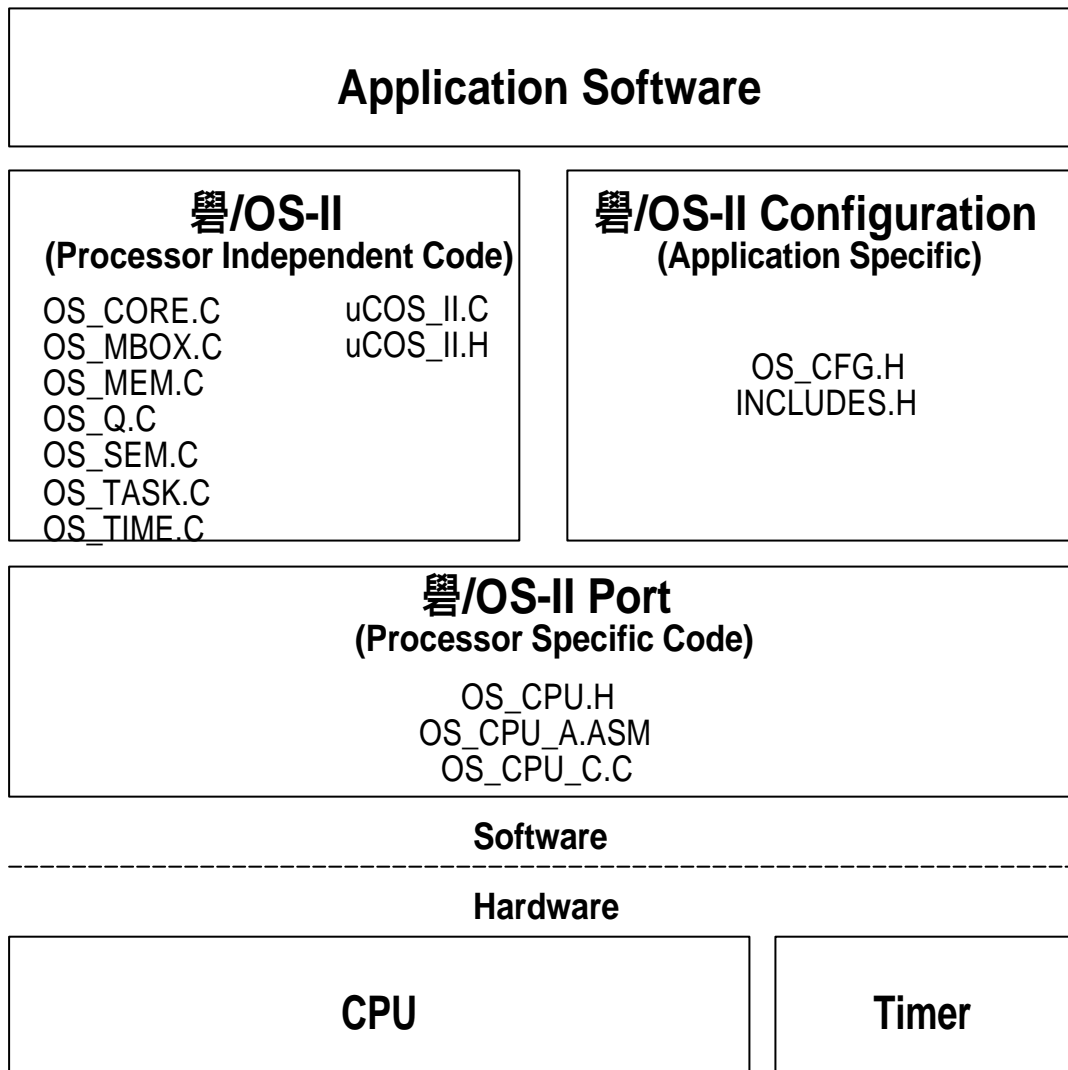
This chapter describes in general terms what needs to be done in order to adapt  $\mu$ C/OS-II to different processors. Adapting a real-time kernel to a microprocessor or a microcontroller is called *port*. Most of  $\mu$ C/OS-II is written in C for portability, however, it is still necessary to write some processor specific code in C and assembly language. Specifically,  $\mu$ C/OS-II manipulates processor registers which can only be done through assembly language. Porting  $\mu$ C/OS-II to different processors is relatively easy because  $\mu$ C/OS-II was designed to be portable. If you already have a port for the processor you are intending to use then you don't need to read this chapter, unless of course you want to know how  $\mu$ C/OS-II's processor specific code works.

A processor can run  $\mu$ C/OS-II if it satisfies the following general requirements:

1. You must have a C compiler for the processor and the C compiler must be able to produce reentrant code.
2. You must be able to disable and enable interrupts from C.
3. The processor must support interrupts and you need to provide an interrupt that occurs at regular intervals (typically between 10 to 100 Hz).
4. The processor must support a hardware stack, and the processor must be able to store a fair amount of data on the stack (possibly many Kbytes).
5. The processor must have instructions to load and store the stack pointer and other CPU registers either on the stack or in memory.

Processors like the Motorola 6805 series do not satisfy requirements #4 and #5 so  $\mu$ C/OS-II cannot run on such processors.





**Figure 8-1,  $\mu$  C/OS-II Hardware/Software Architecture**

Figure 81 shows  $\mu$  C/OS-II's architecture and its relationship with the hardware. When you use  $\mu$  C/OS-II in an application, you are responsible for providing the *Application Software* and the  *$\mu$  C/OS-II Configuration* sections. This book (and diskette) contains all the source code for the *Processor Independent Code* section as well as the *Processor Specific Code* for the Intel 80x86, Real Mode, Large Model. If you intend to use  $\mu$  C/OS-II on a different processor, you will need to either obtain a copy of a port for the processor you intend to use or, write one yourself if the desired processor port is not available. Check the official  $\mu$  C/OS-II WEB site at [www.uCOS-II.com](http://www.uCOS-II.com) for a list of available ports.

Porting  $\mu$  C/OS-II is actually quite straightforward once you understand the subtleties of the target processor and the C compiler you will be using. If your processor and compiler satisfy  $\mu$  C/OS-II's requirements, and you have all the necessary tools at your disposal, porting  $\mu$  C/OS-II consists of:

1. Setting the value of 1 **#define** constants (**OS\_CPU.H**)
2. Declaring 10 data types (**OS\_CPU.H**)
3. Declaring 3 **#define** macros (**OS\_CPU.H**)
4. Writing 6 simple functions in C (**OS\_CPU\_C.C**)

## 5. Writing 4 assembly language functions (**OS\_CPU\_A.ASM**)

Depending on the processor, a port can consist of writing or changing between 50 and 300 lines of code! Porting  $\mu$ C/OS-II could take you anywhere between a few hours to about a week.

Once you have a port of  $\mu$ C/OS-II for your processor, you will need to verify its operation. Testing a multitasking real-time kernel such as  $\mu$ C/OS-II is not as complicated as you may think. You should test your port without application code. In other words, test the operations of the kernel by itself. There are two reasons to do this. First, you don't want to complicate things anymore than they need to be. Second, if something doesn't work, you know that the problem lies in the port as opposed to your application. Start with a couple of simple tasks and only the ticker interrupt service routine. Once you get multitasking going, it's quite simple to add your application tasks.

## 8.00 Development Tools

As previously stated, you need a C compiler for the processor you intend to use in order to port  $\mu$ C/OS-II. Because  $\mu$ C/OS-II is a preemptive kernel, you should only use a C compiler that generates reentrant code. Your C compiler must also be able to support assembly language programming. Most C compiler designed for embedded systems will, in fact, also include an assembler, a linker, and a locator. The linker is used to combine object files (compiled and assembled files) from different modules while the locator will allow you to place the code and data anywhere in the memory map of the target processor. Your C compiler must also provide a mechanism to disable and enable interrupts from C. Some compilers will allow you to insert in-line assembly language statements in your C source code. This makes it quite easy to insert the proper processor instructions to enable and disable interrupts. Other compilers will actually contain language extensions to enable and disable interrupts directly from C.

## 8.01 Directories and Files

The installation program provided on the distribution diskette will install  $\mu$ C/OS-II and the port for the Intel 80x86 (Real Mode, Large Model) on your hard disk. I devised a consistent directory structure to allow you to easily find the files for the desired target processor. If you add a port for another processor, you should consider following the same conventions.

All the ports should be placed under the \SOFTWARE\uCOS-II directory on your hard drive. The source code for each microprocessor or microcontroller port *MUST* be found in either two or three files: **OS\_CPU.H**, **OS\_CPU\_C.C** and optionally, **OS\_CPU\_A.ASM**. The assembly language file is optional because some compilers will allow you to have in-line assembly language and thus, you can place the needed assembly language code directly in **OS\_CPU\_C.C**. The directory in which the port is located determines which processor you are using. Below are examples of the directories where you would store different ports. Note that each have the same file names even though they are totally different targets.

Intel/AMD 80186:	<b>\SOFTWARE\uCOS-II\Ix86S :</b>
	<b>OS_CPU.H</b>
	<b>OS_CPU_A.ASM</b>
	<b>OS_CPU_C.C</b>
	<b>\SOFTWARE\uCOS-II\Ix86L :</b>
	<b>OS_CPU.H</b>
	<b>OS_CPU_A.ASM</b>
	<b>OS_CPU_C.C</b>
Motorola 68HC11:	<b>\SOFTWARE\uCOS-II\68HC11 :</b>
	<b>OS_CPU.H</b>
	<b>OS_CPU_A.ASM</b>

## OS\_CPU.C

### 8.02 INCLUDES.H

As I mentioned in chapter 1, **INCLUDES.H** is a MASTER include file and is found at the top of all .C files as follows:

```
#include "includes.h"
```

**INCLUDES.H** allows every .C file in your project to be written without concerns about which header file will actually be needed. The only drawback to having a master include file is that **INCLUDES.H** may include header files that are not pertinent to the actual .C file being compiled. This means that each file will require extra time to compile. This inconvenience is offset by code portability. You can edit **INCLUDES.H** to add your own header files but, your header files should be added at the end of the list.

### 8.03 OS\_CPU.H

**OS\_CPU.H** contains processor and implementation specific **#defines** constants, macros, and **typedefs**. The general layout of **OS\_CPU.H** is shown in listing 8.1:

```

#ifdef OS_CPU_GLOBALS
#define OS_CPU_EXT
#else
#define OS_CPU_EXT extern
#endif

/*
*****
*
*          DATA TYPES
*          (Compiler Specific)
*****
*/

typedef unsigned char  BOOLEAN;
typedef unsigned char  INT8U;           /* Unsigned  8 bit quantity           */ (1)
typedef signed   char  INT8S;           /* Signed   8 bit quantity           */
typedef unsigned int   INT16U;          /* Unsigned 16 bit quantity           */
typedef signed   int   INT16S;          /* Signed  16 bit quantity           */
typedef unsigned long  INT32U;          /* Unsigned 32 bit quantity           */
typedef signed   long  INT32S;          /* Signed  32 bit quantity           */
typedef float        FP32;              /* Single precision floating point    */ (2)
typedef double       FP64;              /* Double precision floating point    */

typedef unsigned int   OS_STK;          /* Each stack entry is 16-bit wide    */

/*
*****
*
*          Processor Specifics
*****
*/

#define OS_ENTER_CRITICAL() ???         /* Disable interrupts                 */ (3)
#define OS_EXIT_CRITICAL()  ???         /* Enable interrupts                  */
#define OS_STK_GROWTH      1           /* Define stack growth: 1 = Down, 0 = Up */ (4)
#define OS_TASK_SW()       ???         /* Task switch                        */ (5)

```

## Listing 8.1, Contents of OS\_CPU.H

### 8.03.01 *OS\_CPU.H, Compiler Specific Data Types*

Because different microprocessors have different word length, the port of  $\mu$  C/OS-II includes a series of type definitions that ensures portability. Specifically,  $\mu$  C/OS-II's code never makes use of C's **short**, **int** and, **long** data types because they are inherently non-portable. Instead, I defined integer data types that are both portable and intuitive L8.1(1). Also, for convenience, I have included floating-point data types L8.1(2) even though  $\mu$  C/OS-II doesn't make use of floating-point.

The **INT16U** data type, for example, always represents a 16-bit unsigned integer.  $\mu$  C/OS-II and your application code can now assume that the range of values for variables declared with this type is from 0 to 65535. A  $\mu$  C/OS-II port to a 32-bit processor could mean that an **INT16U** is actually declared as an **unsigned short** instead of an **unsigned int**. Where  $\mu$  C/OS-II is concerned, however, it still deals with an **INT16U**.

You must tell  $\mu$  C/OS-II the data type of a task's stack. This is done by declaring the proper C data type for **OS\_STK**. If stack elements on your processor are 32-bit and your compiler documentation specify that an **int** is 32-bit then, you would declare **OS\_STK** as being of type **unsigned int**. All task stacks MUST be declared using **OS\_STK** as its data type.

All you have to do is to consult the compiler's manual and find the standard C data types that corresponds to the types expected by  $\mu$  C/OS-II.

### 8.03.02 *OS\_CPU.H, OS\_ENTER\_CRITICAL() and OS\_EXIT\_CRITICAL()*

$\mu$  C/OS-II like all real-time kernels need to disable interrupts in order to access critical sections of code, and re-enable interrupts when done. This allows  $\mu$  C/OS-II to protect critical code from being entered simultaneously from either multiple tasks or Interrupt Service Routines (ISRs). The interrupt disable time is one of the most important specification that a real-time kernel vendor can provide because it affects the responsiveness of your system to real-time events.  $\mu$  C/OS-II tries to keep the interrupt disable time to a minimum but, with  $\mu$  C/OS-II, interrupt disable time is largely dependent on the processor architecture, and the quality of the code generated by the compiler. Every processor generally provide instructions to disable/enable interrupts and your C compiler must have a mechanism to perform these operations directly from C. Some compilers will allow you to insert in-line assembly language statements in your C source code. This makes it quite easy to insert processor instructions to enable and disable interrupts. Other compilers will actually contain language extensions to enable and disable interrupts directly from C. To hide the implementation method chosen by the compiler manufacturer,  $\mu$  C/OS-II defines two *macros* to disable and enable interrupts: **OS\_ENTER\_CRITICAL()** and **OS\_EXIT\_CRITICAL()**, respectively L8.1(3).

$\mu$  C/OS-II's critical sections are wrapped with **OS\_ENTER\_CRITICAL()** and **OS\_EXIT\_CRITICAL()** as shown below:

```
 $\mu$ C/OS-II Service Function
{
    OS_ENTER_CRITICAL();
    /*  $\mu$ C/OS-II critical code section */
    OS_EXIT_CRITICAL();
}
```

#### Method #1:

The first and simplest way to implement these two macros is to invoke the processor instruction to disable interrupts for **OS\_ENTER\_CRITICAL()** and the enable interrupts instruction for **OS\_EXIT\_CRITICAL()**. There is, however, a little problem with this scenario. If you called the  $\mu$  C/OS-II function with interrupts disabled then, upon return from  $\mu$  C/OS-II, interrupts would be enabled! If you had interrupts disabled, you may have wanted them to be disabled upon return from the  $\mu$  C/OS-II function. In this case, the above implementation would not be adequate.

#### Method #2:

The second way to implement **OS\_ENTER\_CRITICAL()** is to save the interrupt disable status onto the stack and then, disable interrupts. **OS\_EXIT\_CRITICAL()** would simply be implemented by restoring the interrupt status from the stack. Using this scheme, if you called a  $\mu$  C/OS-II service with either interrupts enabled or disabled then, the status would be preserved across the call. If you call a  $\mu$  C/OS-II service with interrupts disabled, you are potentially extending the interrupt latency of your application. Your application can use **OS\_ENTER\_CRITICAL()** and **OS\_EXIT\_CRITICAL()** to also protect critical sections of code. Be careful, however, because your application will 'crash' if you have interrupts disabled before calling a service such as **OSTimeDly()**. This will happen because the task will be suspended until time expires but, because interrupts are disabled, you would never service the tick interrupt! Obviously, all the PEND calls are also subject to this problem so, be careful. As a general rule, you should always call  $\mu$  C/OS-II services with interrupts enabled!

The question is thus, which one is better? Well, that all depends on what you are willing to sacrifice. If you don't care in your application whether interrupts are enabled after calling a  $\mu$  C/OS-II service then, you should opt for the first method because of performance. If you want to preserve the interrupt disable status across  $\mu$  C/OS-II service calls then obviously the second method is for you.

Just to give you an example, disabling interrupts on an Intel 80186 is done by executing the **STI** instructions and enabling interrupts is done by executing the **CLI** instruction. You can thus implement the macros as follows:

```
#define OS_ENTER_CRITICAL()  asm CLI
#define OS_EXIT_CRITICAL()   asm STI
```

Both the **CLI** and **STI** instructions execute in less than 2 clock cycles each on this processor (i.e. total of 4 cycles). To preserve the interrupt status you would need to implement the macros as follows:

```
#define OS_ENTER_CRITICAL()  asm PUSHF; CLI
#define OS_EXIT_CRITICAL()   asm POPF
```

In this case, **OS\_ENTER\_CRITICAL( )** would consume 12 clock cycles while **OS\_EXIT\_CRITICAL( )** would use up another 8 clock cycles (i.e. a total of 20 cycles). Preserving the state of the interrupt disable status would thus take 16 clock cycles longer than simply disabling/enabling interrupts (at least on the 80186). Obviously, if you have a faster processor such as an Intel Pentium-II then, the difference would be minimal.

### 8.03.03 *OS\_CPU.H, OS\_STK\_GROWTH*

The stack on most microprocessors and microcontrollers grows from high-memory to low-memory. There are, however, some processors that work the other way around.  $\mu$ C/OS-II has been designed to be able to handle either flavor. This is accomplished by specifying to  $\mu$ C/OS-II which way the stack grows through the configuration constant **OS\_STK\_GROWTH** L8.1(4) as shown below:

Set **OS\_STK\_GROWTH** to 0 for Low to High memory stack growth.

Set **OS\_STK\_GROWTH** to 1 for High to Low memory stack growth.

### 8.03.04 *OS\_CPU.H, OS\_TASK\_SW()*

**OS\_TASK\_SW( )** L8.1(5) is a macro that is invoked when  $\mu$ C/OS-II switches from a low-priority task to the highest-priority task. **OS\_TASK\_SW( )** is always called from task level code. Another mechanism, **OSIntExit( )**, is used to perform a context switch when an ISR makes a higher priority task ready for execution. A context switch simply consists of saving the processor registers on the stack of the task being suspended, and restoring the registers of the higher-priority task from its stack.

In  $\mu$ C/OS-II, the stack frame for a ready task always looks as if an interrupt has just occurred and all processor registers were saved onto it. In other words, all that  $\mu$ C/OS-II has to do to run a ready task is to restore all processor registers from the task's stack and execute a return from interrupt. To switch context, you should implement **OS\_TASK\_SW( )** so that you simulate an interrupt. Most processors provide either software interrupt or **TRAP** instructions to accomplish this. The ISR or trap handler (also called the 'exception handler') MUST vector to the assembly language function **OSCtxSw( )** (see section 8.04.02).

For example, a port for an Intel or AMD 80x86 processor would use an **INT** instruction. The interrupt handler would need to vector to **OSCtxSw( )**. A port for the Motorola 68HC11 processor would most likely use the **SWI** instruction. Again, the **SWI** handler would be **OSCtxSw( )**. Finally, a port for a Motorola 680x0/CPU32 processor would probably use one of the 16 **TRAP** instructions. Of course, the selected **TRAP** handler would be none other than **OSCtxSw( )**.

There are some processors like the Zilog Z80 that do not provide a software interrupt mechanism. In this case, you would need to simulate the stack frame as closely to an interrupt stack frame as you can. In this case,

**OS\_TASK\_SW()** would simply call **OSCtxSw()** instead of vector to it. The Z80 is a processor that has been ported to  $\mu$  C/OS and thus would be portable to  $\mu$  C/OS-II.

## 8.04 OS\_CPU\_A.ASM

A  $\mu$  C/OS-II port requires that you write four fairly simple assembly language functions:

```
OSStartHighRdy()  
OSCtxSw()  
OSIntCtxSw()  
OSTickISR()
```

If your compiler supports in-line assembly language code, you could actually place all the processor specific code into **OS\_CPU\_C.C** instead of having a separate assembly language file.

### 8.04.01 OS\_CPU\_A.ASM, OSStartHighRdy()

This function is called by **OSStart()** to start the highest priority task ready-to-run. Before you can call **OSStart()**, however, you MUST have created at least one of your tasks (see **OSTaskCreate()** and **OSTaskCreateExt()**). **OSStartHighRdy()** assumes that **OSTCBHighRdy** points to the task control block of the task with the highest priority. As mentioned previously, in  $\mu$  C/OS-II, the stack frame for a ready task always looks as if an interrupt has just occurred and all processor registers were saved onto it. To run the highest priority task all you need to do is restore all processor registers from the task's stack in the proper order and, execute a return from interrupt. To simplify things, the stack pointer is always stored at the beginning of the task control block (i.e. its **OS\_TCB**). In other words, the stack pointer of the task to resume is always stored at offset 0 in the **OS\_TCB**.

Note that **OSStartHighRdy()** MUST call **OSTaskSwHook()** because we are basically doing a 'half' context switch – we are restoring the registers of the highest priority task. **OSTaskSwHook()** can examine **OSRunning** to tell it whether **OSTaskSwHook()** was called from **OSStartHighRdy()** (i.e. if **OSRunning** is **FALSE**) or from a regular context switch (i.e. **OSRunning** is **TRUE**).

**OSStartHighRdy()** MUST also set **OSRunning** to **TRUE** before the high priority task is restored (but after calling **OSTaskSwHook()**).

### 8.04.02 OS\_CPU\_A.ASM, OSCtxSw()

As previously mentioned, a task level context switch is accomplished by issuing a software interrupt instruction or, depending on the processor, executing a **TRAP** instruction. The interrupt service routine, trap or exception handler MUST vector to **OSCtxSw()**.

The sequence of events that leads  $\mu$  C/OS-II to vector to **OSCtxSw()** is as follows. The current task calls a service provided by  $\mu$  C/OS-II which causes a higher priority task to be ready-to-run. At the end of the service call,  $\mu$  C/OS-II calls the function **OSSched()** which concludes that the current task is no longer the most important task to run. **OSSched()** loads the address of the highest priority task into **OSTCBHighRdy** and then executes the software interrupt or trap instruction by invoking the macro **OS\_TASK\_SW()**. Note that the variable **OSTCBCur** already contains a pointer to the current task's Task Control Block, **OS\_TCB**. The software interrupt instruction (or trap) forces some of the processor registers (most likely the return address and the processor's status word) onto the current task's stack and the processor then vectors to **OSCtxSw()**.

The pseudo code of what needs to be done by **OSCtxSw( )** is shown in listing 8.2. This code must be written in assembly language because you cannot access CPU registers directly from C.

```
void OSCtxSw(void)
{
    Save processor registers;
    Save the current task's stack pointer into the current task's OS_TCB:
        OSTCBCur->OSTCBStkPtr = Stack pointer;
    Call user definable OSTaskSwHook();
    OSTCBCur = OSTCBHighRdy;
    OSPrioCur = OSPrioHighRdy;
    Get the stack pointer of the task to resume:
        Stack pointer = OSTCBHighRdy->OSTCBStkPtr;
    Restore all processor registers from the new task's stack;
    Execute a return from interrupt instruction;
}
```

### **Listing 8.2, Pseudo code for OSCtxSw()**

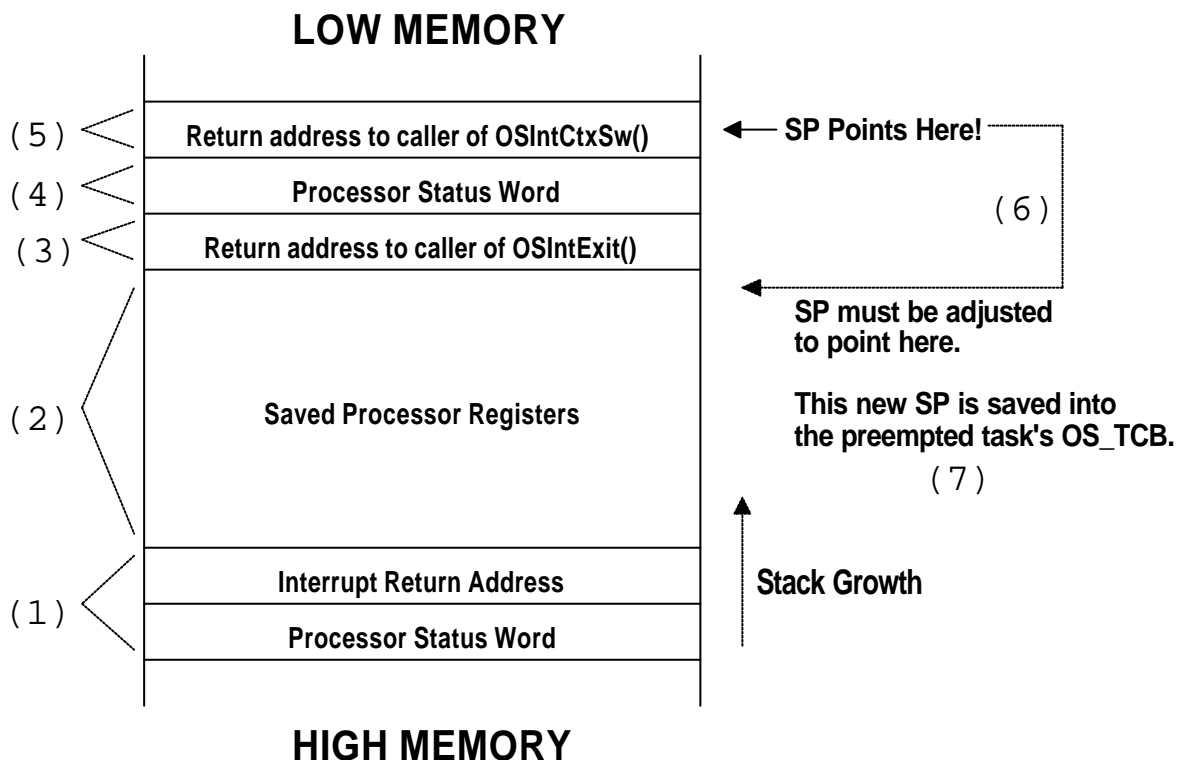
You should note that interrupts are disabled during **OSCtxSw( )** and also during execution of the user definable function **OSTaskSwHook( )**.



### 8.04.03 OS\_CPU\_A.ASM, OSIntCtxSw()

**OSIntCtxSw()** is a function that is called by **OSIntExit()** to perform a context switch from an ISR. Because **OSIntCtxSw()** is called from an ISR, it is assumed that all the processor registers are properly saved onto the interrupted task's stack. In fact, there are more things on the stack frame than we need. **OSIntCtxSw()** will thus have to clean up the stack so that the interrupted task is left with just the proper stack frame content.

To understand what needs to be done in **OSIntCtxSw()**, let's look at the sequence of events that leads  $\mu$  C/OS-II to call **OSIntCtxSw()**. You may want to refer to figure 8-2 to help understand the following description. We will assume that interrupts are not nested (i.e. an ISRs will not be interrupted), interrupts are enabled, and the processor is executing task level code. When an interrupt arrives, the processor completes the current instruction, recognizes the interrupt and initiates an interrupt handling procedure. This generally consist of pushing the processor status register and the return address of the interrupted task onto the stack F8-2(1). The order and which registers are pushed onto the stack is irrelevant.



**Figure 8-2, Stack contents during an ISR**

The CPU then vectors to the proper ISR.  $\mu$  C/OS-II requires that your ISR begins by saving the rest of the processor registers F8-2(2). Once the registers are saved,  $\mu$  C/OS-II requires that you either call **OSIntEnter()** or, that you increment the global variable **OSIntNesting** by one. At this point, the interrupted task's stack frame only contains the register contents of the interrupted task. The ISR can now start servicing the interrupting device and possibly, make a higher priority task ready. This would occur if the ISR sends a message to a task (by calling **OSMboxPost()** or **OSQPost()**), resume a task (by calling **OSTaskResume()**), invoke

**OSTimeTick()** or **OSTimeDlyResume()**. Let us assume that a higher priority task is made ready to run.

$\mu$  C/OS-II requires that your ISR calls **OSIntExit()** when the ISR completes servicing the interrupting device. **OSIntExit()** basically tell  $\mu$  C/OS-II that it's time to return back to task level code. The call to **OSIntExit()** causes the return address of the caller to be pushed onto the interrupted task's stack F8-2(3).

**OSIntExit()** starts by disabling interrupts because it needs to execute critical code. Depending on how **OS\_ENTER\_CRITICAL()** is implemented (see section 8.03.02), the processor's status register could be pushed onto the interrupted task's stack F8-2(4). **OSIntExit()** notices that the interrupted task is no longer the task that needs to run because a higher priority task is now ready. In this case, the pointer **OSTCBHighRdy** is made to point to the new task's **OS\_TCB** and **OSIntExit()** calls **OSIntCtxSw()** to perform the context switch. Calling **OSIntCtxSw()** causes the return address to be pushed onto the interrupted task's stack F8-2(5).

As we are switching context, we only want to leave items F8-2(1) and F8-2(2) on the stack and ignore items F8-2(3), F8-2(4) and F8-2(5). This is accomplished by adding a 'constant' to the stack pointer F8-2(6). The *exact* amount of stack adjustment *must* be known and this value greatly depends on the processor being ported (an address can be 16-bit, 32-bit or 64-bit), the compiler used, compiler options, memory model, etc. Also, the processor status word could be 8, 16, 32 or even 64-bit wide and, **OSIntExit()** may allocate local variables. Some processors allow you to directly add a constant to the stack pointer, others don't. In the latter case, you can simply execute the appropriate number of pops instructions to one of the processor registers to accomplish the same thing. Once the stack is adjusted, the new stack pointer can be saved into the **OS\_TCB** of the task being switched out F8-2(7).

**OSIntCtxSw()** is the only function in  $\mu$  C/OS-II (and also  $\mu$  C/OS) that is compiler specific and has generated more e-mail than any other aspect of  $\mu$  C/OS. If your port crashes after a few context switches then, you should suspect that the stack is not being properly adjusted in **OSIntCtxSw()**.

The pseudo code in listing 8.3 shows what needs to be done by **OSIntCtxSw()**. This code must be written in assembly language because you cannot access CPU registers directly from C. If your C compiler supports in-line assembly, you can put the code for **OSIntCtxSw()** in **OS\_CPU\_C.C** instead of **OS\_CPU\_A.ASM**. As you can see, except for the first line, the code is identical to **OSCtxSw()**. You can thus reduce the amount of code in the port by 'jumping' to the appropriate section of code in **OSCtxSw()**.

```
void OSIntCtxSw(void)
{
    Adjust the stack pointer to remove calls to:
        OSIntExit(),
        OSIntCtxSw() and possibly the push of the processor status word;
    Save the current task's stack pointer into the current task's OS_TCB:
        OSTCBCur->OSTCBStkPtr = Stack pointer;
    Call user definable OSTaskSwHook();
    OSTCBCur = OSTCBHighRdy;
    OSPrioCur = OSPrioHighRdy;
    Get the stack pointer of the task to resume:
        Stack pointer = OSTCBHighRdy->OSTCBStkPtr;
    Restore all processor registers from the new task's stack;
    Execute a return from interrupt instruction;
}
```

**Listing 8.3, Pseudo code for OSIntCtxSw()**

#### 8.04.04 *OS\_CPU\_A.ASM, OSTickISR()*

$\mu$ C/OS-II requires that you provide a periodic time source to keep track of time delays and timeouts. A 'tick' should occur between 10 and 100 times per second, or Hertz. To accomplish this, you can either dedicate a hardware timer, or obtain 50/60 Hz from an AC power line.

You MUST enable ticker interrupts AFTER multitasking has started, i.e. after calling **OSStart()**. In other words, you should initialize and tick interrupts in the first task that executes following a call to **OSStart()**. A common mistake is to enable ticker interrupts between calling **OSInit()** and **OSStart()** as shown in listing 8.4:

```
void main(void)
{
    .
    .
    OSInit();           /* Initialize  $\mu$ C/OS-II           */
    .
    .
    /* Application initialization code ...           */
    /* ... Create at least one task by calling OSTaskCreate() */
    .
    .
    Enable TICKER interrupts; /* DO NOT DO THIS HERE!!! */
    .
    .
    OSStart();          /* Start multitasking           */
}
```

#### Listing 8.4, Incorrect place to start the tick interrupt.

What could happen (and it has happened) is that the tick interrupt could be serviced before  $\mu$ C/OS-II starts the first task. At this point,  $\mu$ C/OS-II is in an unknown state and will cause your application to crash.

The pseudo code for the tick ISR is shown in listing 8.5. This code must be written in assembly language because you cannot access CPU registers directly from C. If your processor is able to increment **OSIntNesting** with a single instruction then, there is no need for you to call **OSIntEnter()**. Incrementing **OSIntNesting** is much quicker than going through the overhead of the function call and return. **OSIntEnter()** only increments the **OSIntNesting**, while protecting that increment in a critical section.

```
void OSTickISR(void)
{
    Save processor registers;
    Call OSIntEnter() or increment OSIntNesting;

    Call OSTimeTick();

    Call OSIntExit();
    Restore processor registers;
    Execute a return from interrupt instruction;
}
```

#### Listing 8.5, Pseudo code for Tick ISR

## 8.05 OS\_CPU\_C.C

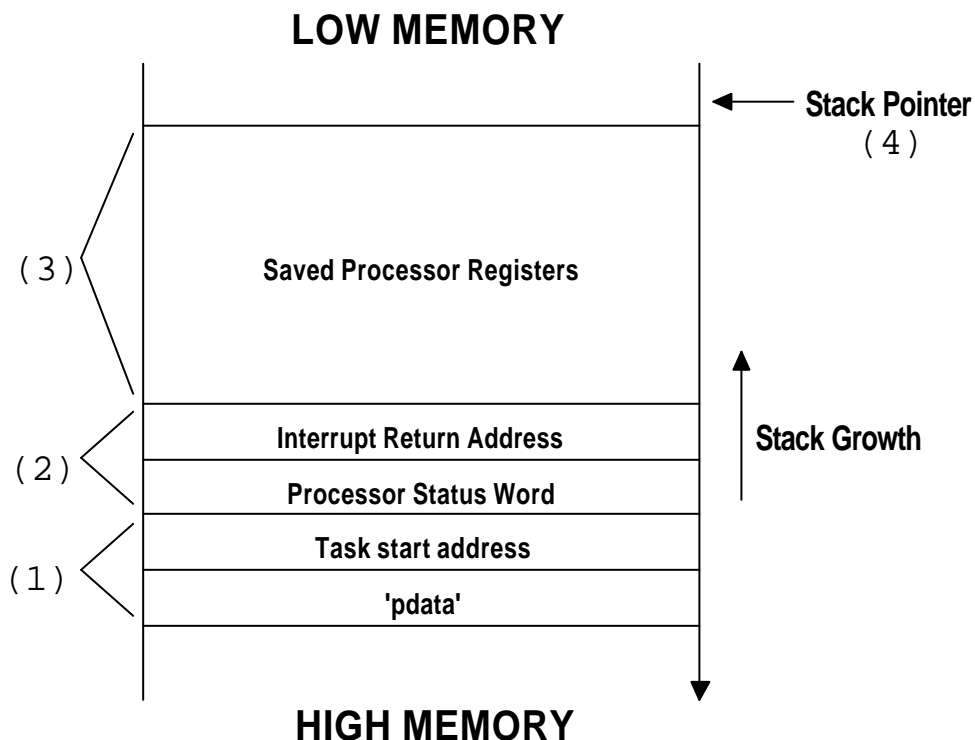
A  $\mu$ C/OS-II port requires that you write six fairly simple C functions:

```
OSTaskStkInit()  
OSTaskCreateHook()  
OSTaskDelHook()  
OSTaskSwHook()  
OSTaskStatHook()  
OSTimeTickHook()
```

The only function that is actually necessary is **OSTaskStkInit()**. The other five functions **MUST** be declared but don't need to contain any code inside them.

### 8.05.01 OS\_CPU\_C.C, OSTaskStkInit()

This function is called by **OSTaskCreate()** and **OSTaskCreateExt()** to initialize the stack frame of a task so that the stack looks as if an interrupt just occurred and all the processor registers were pushed onto that stack. Figure 8-3 shows what **OSTaskStkInit()** will put on the stack of the task being created. Note that figure 8-3 assumes a stack growing from high-memory to low-memory. The discussion that follows applies just as well for a stack growing in the opposite direction.



### Figure 8-3, Stack frame initialization with 'pdata' passed on the stack

When you create a task, you specify to `OSTaskCreate()` or `OSTaskCreateExt()` the start address of the task, you pass it a pointer called **pdata**, the task's top-of-stack and the task's priority. `OSTaskCreateExt()` requires additional arguments but these are irrelevant in discussing `OSTaskStkInit()`. To properly initialize the stack frame, `OSTaskStkInit()` only requires the first three arguments just mentioned in addition to an 'option' value which is only available in `OSTaskCreateExt()`.

Recall that under  $\mu$  C/OS-II, a task is written as shown below. A task is an infinite loop but otherwise looks just like any other C function. When the task is started by  $\mu$  C/OS-II, it will receive an argument just as if it was called by another function.

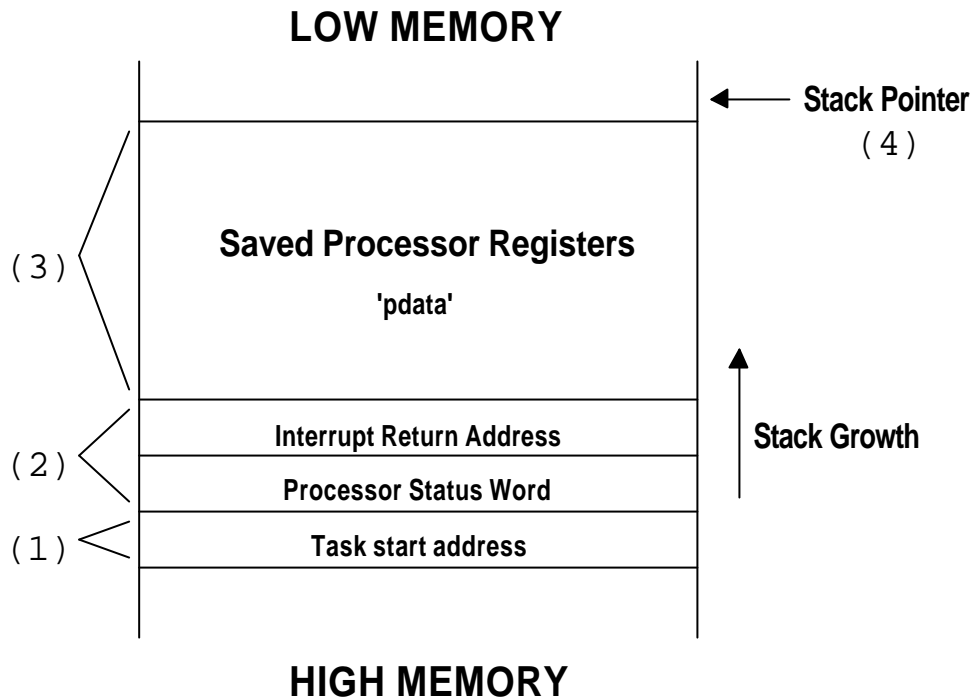
```
void MyTask (void *pdata)
{
    /* Do something with argument 'pdata' */
    for (;;) {
        /* Task code */
    }
}
```

If I were to call **MyTask()** from another function, the C compiler would push the argument onto the stack followed by the return address of the function calling **MyTask()**. Some compilers would actually pass **pdata** in one or more registers. I'll discuss this situation later. Assuming **pdata** is pushed onto the stack, `OSTaskStkInit()` simply simulates this scenario and loads the stack accordingly F8-3(1). It turns out that, unlike a C function call, however, we really don't know what the return address of the caller is. All we have is the start address of the task, not the return address of the function that would have called this function (i.e. task)! It turns out that we don't really care because a task is not supposed to return back to another function anyway.

At this point, we need to put on the stack the registers that are automatically pushed by the processor when it recognizes and starts servicing an interrupt. Some processors will actually stack all of its registers while others will stack just a few. Generally speaking, a processor will stack at least the value of the program counter for the instruction to return to upon returning from an interrupt and, the processor status word F8-3(2). You must obviously match the order exactly.

Next, you need to put on the stack the rest of the processor registers F8-3(3). The stacking order depends on whether your processor gives you a choice or not. Some processors have one or more instructions that pushes many registers at once. You would thus have to emulate the stacking order of such instruction(s). To give you an example, the Intel 80x86 has the **PUSHA** instruction which pushes 8 registers onto the stack. On the Motorola 68HC11 processor, all the registers are automatically pushed onto the stack during an interrupt response so, you will also need to match the same stacking order.

Now it's time to come back to the issue of what to do if your C compiler passes the **pdata** argument in registers instead of on the stack. You will need to find out from the compiler documentation the register where **pdata** would actually be stored in. The stack frame would look as shown in figure 8-4. **pdata** would simply be placed on the stack in the area where you would save the corresponding register.



**Figure 8-4, Stack frame initialization with ‘pdata’ passed in register**

Once you’ve completed the initialization of the stack, **OSTaskStkInit()** will need to return the address where the stack pointer would point to after the stacking is complete F8-3(4). **OSTaskCreate()** or **OSTaskCreateExt()** will take this address and save it in the task control block (**OS\_TCB**). The processor documentation will tell you whether the stack pointer needs to point to the next ‘free’ location on the stack or, the location of the last stored value. For example, on an Intel 80x86 processor, the stack pointer points to the last stored data while on a Motorola 68HC11 processor, it points at the next free location.

### **8.05.02 OS\_CPU\_C.C, OSTaskCreateHook()**

**OSTaskCreateHook()** is called whenever a task is created by either **OSTaskCreate()** or **OSTaskCreateExt()**. This allows you or the user of your port to extend the functionality of  $\mu$ C/OS-II. **OSTaskCreateHook()** is called when  $\mu$ C/OS-II is done setting up its internal structures but before the scheduler is called. Interrupts are disabled when this function is called. Because of this, you should keep the code in this function to a minimum because it directly affects interrupt latency.

When called, **OSTaskCreateHook()** receives a pointer to the **OS\_TCB** of the task created and can thus access all of the structure elements. **OSTaskCreateHook()** has limited capability when the task is created with **OSTaskCreate()**. However, with **OSTaskCreateExt()**, you get access to a TCB extension pointer (**OSTCBExtPtr**) in **OS\_TCB** which can be used to access additional data about the task such as the contents of floating-point registers, MMU (Memory Management Unit) registers, task counters, debug information, etc.

The code for **OSTaskCreateHook()** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**. This allows the user of your port to redefine all the hook functions in a different file. Obviously, users of your port would need access to the source of your port to compile your port with **OS\_CPU\_HOOKS\_EN** set to 0 in order to prevent multiply defined symbols at link time.

### 8.05.03 *OS\_CPU\_C.C, OSTaskDelHook()*

**OSTaskDelHook()** is called whenever a task is deleted. **OSTaskDelHook()** is called before unlinking the task from  $\mu$ C/OS-II's internal linked list of active tasks. When called, **OSTaskDelHook()** receives a pointer to the task control block (**OS\_TCB**) of the task being deleted and can thus access all of the structure elements. **OSTaskDelHook()** can see if a TCB extension has been created (non-NULL pointer). **OSTaskDelHook()** would thus be responsible for performing cleanup operations. **OSTaskDelHook()** is not expected to return anything.

The code for **OSTaskDelHook()** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**.

### 8.05.04 *OS\_CPU\_C.C, OSTaskSwHook()*

**OSTaskSwHook()** is called whenever a task switch occurs. This happens whether the task switch is performed by **OSCtxSw()** or **OSIntCtxSw()**. **OSTaskSwHook()** can directly access **OSTCBCur** and **OSTCBHighRdy** because these are global variables. Of course, **OSTCBCur** points to the **OS\_TCB** of the task being switched out and **OSTCBHighRdy** points to the **OS\_TCB** of the new task. You should note that interrupts are always disabled during the call to **OSTaskSwHook()** and thus, you should keep any additional code to a minimum since it will affect interrupt latency. **OSTaskSwHook()** doesn't have any arguments and is not expected to return anything.

The code for **OSTaskSwHook()** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**.

### 8.05.05 *OS\_CPU\_C.C, OSTaskStatHook()*

**OSTaskStatHook()** is called once per second by **OSTaskStat()**. You can extend the statistics capability with **OSTaskStatHook()**. For instance, you could keep track and display the execution time of each task, the percentage of the CPU that is used by each task, how often each task executes and more. **OSTaskStatHook()** doesn't have any arguments and is not expected to return anything.

The code for **OSTaskStatHook()** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**.

### 8.05.06 *OS\_CPU\_C.C, OStimeTickHook()*

**OStimeTickHook()** is called by **OStimeTick()** at every system tick. In fact, **OStimeTickHook()** is called before a tick is actually processed by  $\mu$ C/OS-II to give your port or the application first claim on the tick. **OStimeTickHook()** doesn't have any arguments and is not expected to return anything.

The code for **OStimeTickHook()** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**.

# OSTaskCreateHook()

void OSTaskCreateHook(OS\_TCB \*ptcb)

File	Called from	Code enabled by
OS_CPU_C.C	OSTaskCreate() and OSTaskCreateExt()	OS_CPU_HOOKS_EN

This function is called whenever a task is created. **OSTaskCreateHook()** is called after a TCB has been allocated and initialized and, the stack frame of the task is also initialized. **OSTaskCreateHook()** allows you to extend the functionality of the task creation function with your own features. For example, you can initialize and store the contents of floating-point registers, MMU registers or anything else that can be associated with a task. You would, however, typically store this additional information in memory that would be allocated by your application. You could also use **OSTaskCreateHook()** to trigger an oscilloscope, a logic analyzer or set a breakpoint.

## Arguments

**ptcb** is a pointer to the task control block of the task created.

## Returned Value

NONE

## Notes/Warnings

Interrupts are disabled when this function is called. Because of this, you should keep the code in this function to a minimum because it can directly affects interrupt latency.

## Example

This example assumes that you created a task using the **OSTaskCreateExt()** function because it is expecting to have the **.OSTCBExtPtr** field in the task's **OS\_TCB** contain a pointer to storage for floating-point registers.

```
void OSTaskCreateHook (OS_TCB *ptcb)
{
    if (ptcb->OSTCBExtPtr != (void *)0) {
        /* Save contents of floating-point registers in .. */
        /* .. the TCB extension                               */
    }
}
```

# OSTaskDelHook()

void OSTaskDelHook(OS\_TCB \*ptcb)

File	Called from	Code enabled by
OS_CPU_C.C	OSTaskDel()	OS_CPU_HOOKS_EN

This function is called whenever you delete a task by calling **OSTaskDel()**. You could thus dispose of memory you would have allocated through the task create hook, **OSTaskCreateHook()**. **OSTaskDelHook()** is called just before the TCB is removed from the TCB chain. You could also use **OSTaskCreateHook()** to trigger an oscilloscope, a logic analyzer or set a breakpoint.



### Arguments

**ptcb** is a pointer to the task control block of the task being deleted.

### Returned Value

NONE

### Notes/Warnings

Interrupts are disabled when this function is called. Because of this, you should keep the code in this function to a minimum because it directly affects interrupt latency.

### Example

```
void OSTaskDelHook (OS_TCB *ptcb)
{
    /* Output signal to trigger an oscilloscope */
}
```

# OSTaskSwHook()

`void OSTaskSwHook(void)`

File	Called from	Code enabled by
OS_CPU_C.C	OSCtxSw() and OSIntCtxSw()	OS_CPU_HOOKS_ENA

This function is called whenever a context switch is performed. The global variable **OSTCBHighRdy** points to the TCB of the task that will be getting the CPU while **OSTCBCur** will point to the TCB of the task being switched out. **OSTaskSwHook ( )** is called just after saving the task's registers and saving the stack pointer into the current task's TCB. You can use this function to save the contents of floating-point registers, MMU registers, keep track of task execution time, keep track of how many times the task has been switched-in, and more.

### Arguments

NONE

### Returned Value

NONE

### Notes/Warnings

Interrupts are disabled when this function is called. Because of this, you should keep the code in this function to a minimum because it directly affects interrupt latency.

### Example

```
void OSTaskSwHook (void)
{
    /* Save floating-point registers in current task's TCB ext. */
}
```

```

    /* Restore floating-point registers in current task's TCB ext. */
}

```

# OSTaskStatHook()

**void OSTaskStatHook(void)**

File	Called from	Code enabled by
OS_CPU_C.C	OSTaskStat()	OS_CPU_HOOKS_EN

This function is called every second by  $\mu$  C/OS-II's statistic task and allows you to add your own statistics.

## Arguments

NONE

## Returned Value

NONE

## Notes/Warnings

The statistic task starts executing about 5 seconds after calling **OSStart()**. Note that this function will not be called if either **OS\_TASK\_STAT\_EN** or **OS\_TASK\_CREATE\_EXT\_EN** is set to 0.

## Example

```

void OSTaskStatHook (void)
{
    /* Compute the total execution time of all the tasks      */
    /* Compute the percentage of execution of each task      */
}

```

# OSTimeTickHook()

**void OSTimeTickHook(void)**

File	Called from	Code enabled by
OS_CPU_C.C	OSTimeTick()	OS_CPU_HOOKS_EN

This function is called by **OSTimeTick()** which in turn is called whenever a clock tick occurs. **OSTimeTickHook()** is called immediately upon entering **OSTimeTick()** to allow execution of time critical code in your application.

You can also use this function to trigger an oscilloscope for debugging, trigger a logic analyzer, establish a breakpoint for an emulator, and more.

## Arguments

NONE

## Returned Value

NONE

#### Notes/Warnings

**OSTimeTick()** is generally called by an ISR and thus, the execution time of the tick ISR will be increased by the code you provide in this function. Interrupts may or may not be enabled when **OSTimeTickHook()** is called depending how the processor port has been implemented. If interrupts are disabled, this function will affect interrupt latency.

#### Example

```
void OSTimeTickHook (void)
{
    /* Trigger an oscilloscope          */
}
```

## Chapter 9

# 80x86, Large Model Port

This chapter describes how  $\mu$  C/OS-II has been ported to the Intel 80x86 series of processors running in *Real Mode* and for the *Large Model*. This port applies to the following CPUs:

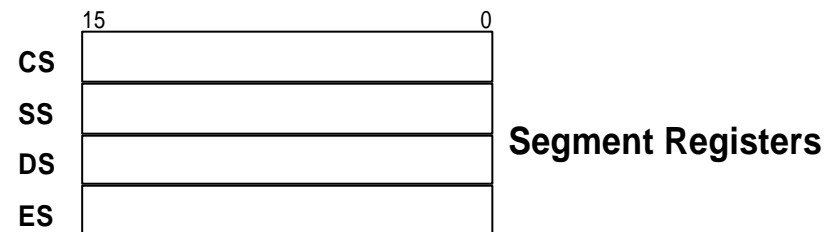
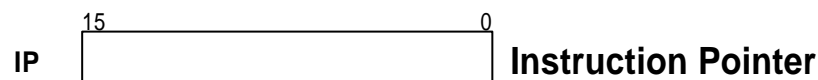
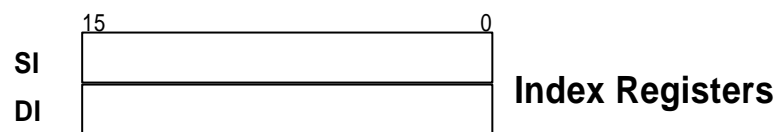
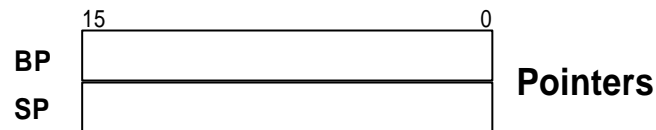
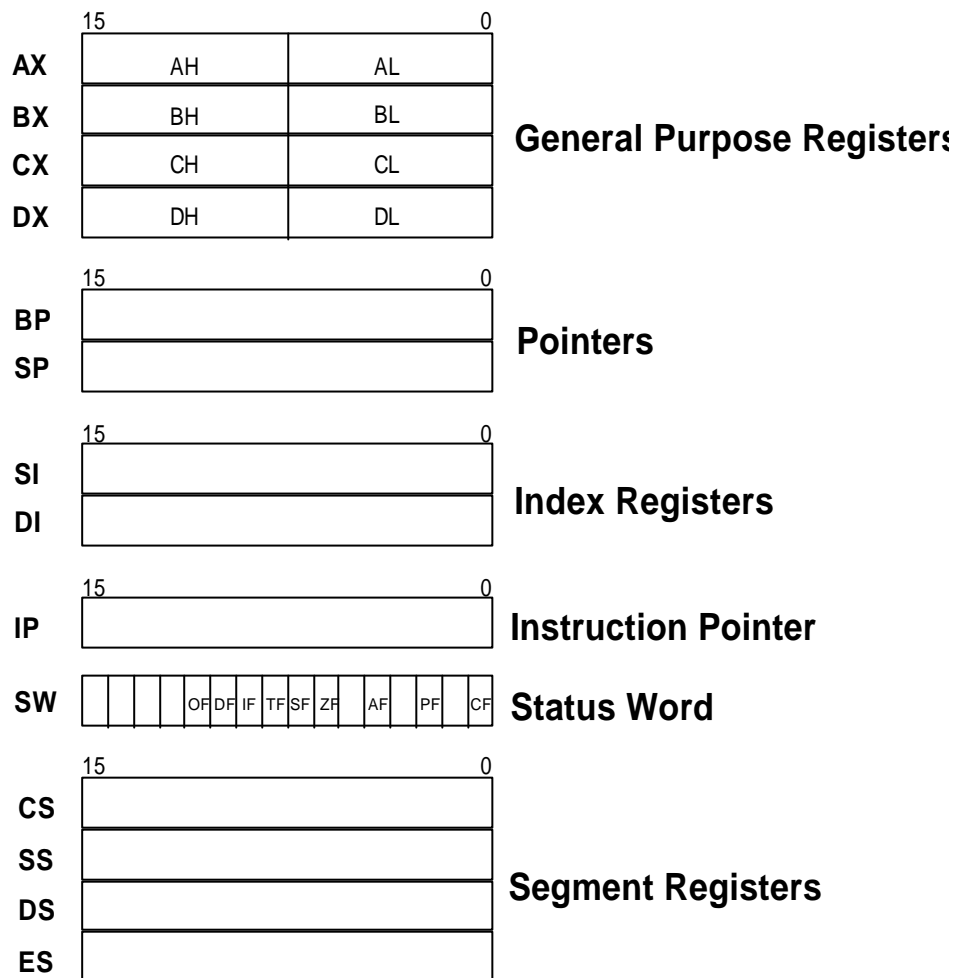
- 80186
- 80286
- 80386
- 80486
- Pentium
- Pentium-II

It turns out that the port can run on most 80x86 compatible CPU manufactured by AMD, Cyrix, NEC (V-series) and others. I used Intel here in a generic fashion. There are literally millions of 80x86 CPU being sold each year. Most of these end up in desktop type computers but, a growing number of processors are making their way in embedded systems. The fastest processors (i.e. the Pentium-IIs) should reach 1000 MHz by year 2000.

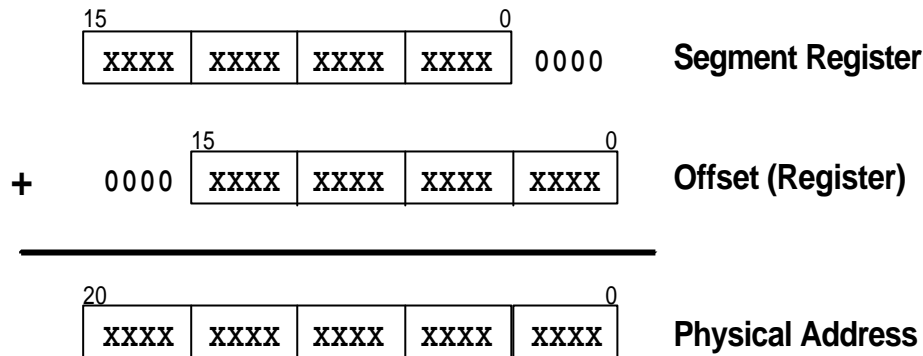
Most C compiler that support 80x86 processors running in real mode offer different memory models, each suited for a different program and data size. Each model uses memory differently. The Large Model allows your application (code and data) to reside in a 1 MegaBytes memory space. Pointers in this model require 32-bits although they can only address up to 1 MegaBytes! The next section will show why a 32-bit pointer in this model can only address 20-bits worth of memory.

This port can also be adapted to run on the 8086 processor but requires that you replace the use of the **PUSHA** instruction with the proper number of **PUSH** instructions.

Figure 9-1 shows the programming model of an 80x86 processor running in real mode. All registers are 16-bit wide and they all need to be saved during a context switch.



The 80x86 provides a clever mechanism to access up to 1 Mbytes of memory with its 16-bit registers. Memory addressing relies on using a *segment* and an *offset* register. Physical address calculation is done by shifting a segment register by 4 (multiplying it by 16) and adding one of six other registers (**AX**, **BP**, **SP**, **SI**, **DI** or **IP**). The result is a 20-bit address which can access up to 1 Mbytes. Figure 9-2 shows how the registers are combined. Each segment points to a block of 16 memory locations called a *paragraph*. A 16-bit segment register can point to any of 65,536 different paragraphs of 16 bytes and thus address 1,048,576 bytes. Because the offset is also 16-bit, a single segment of code cannot exceed 64 Kbytes. In practice, however, programs are made up of many smaller segments.



**Figure 9-2, Addressing with a Segment and an Offset**

The *Code Segment* register (CS) points to the base of the program currently executing, the *Stack Segment* register (SS) points to the base of the stack, the *Data Segment* register (DS) points to the base of one data area while the *Extra Segment* register (ES) points to the base of another area where data may be stored. Each time the CPU needs to generate a memory address, one of the segment registers is automatically chosen and its contents is added to an offset. It is common to find the segment-colon-offset notation in literature to reference a memory location. For example, 1000:00FF represents physical memory location **0x100FF**.

## 9.00 Development Tools

I used the Borland C/C++ V3.1 compiler along with the Borland Turbo Assembler to port and test the 80x86 port. The compiler generates reentrant code and provides in-line assembly language instructions to be inserted in C code. Once compiled, the code is executed on a PC. I tested the code on a Pentium-II based computer running the Microsoft Windows 95 operating system. In fact, I configured the compiler to generate a DOS executable which was run in a DOS window.

This port will run on most C compilers as long as the compiler can generate Real-Mode code. You will most likely have to change some of the compiler options and assembler directives.

### 9.01 Directories and Files

The installation program provided on the distribution diskette will install the port for the Intel 80x86 (Real Mode, Large Model) on your hard disk. The port is found under the **\SOFTWARE\uCOS-II\Ix86L** directory on your hard drive. The directory name stands for **Intel 80x86 Real Mode, Large Model**. The source code for the port is found in the following files: **OS\_CPU.H**, **OS\_CPU\_C.C** and, **OS\_CPU\_A.ASM**.

### 9.02 INCLUDES.H

**INCLUDES.H** is a MASTER include file and is found at the top of all .C files. **INCLUDES.H** allows every .C file in your project to be written without concerns about which header file will actually be needed. The only drawback to having a master include file is that **INCLUDES.H** may include header files that are not pertinent to the actual .C file being compiled. This means that each file will require extra time to compile. This inconvenience is offset by code

portability. You can edit **INCLUDES.H** to add your own header files but, your header files should be added at the end of the list. Listing 9.1 shows the contents of **INCLUDES.H** for the 80x86 port.

```
#include <stdio.h>
#include <string.h>
#include <ctype.h>
#include <stdlib.h>
#include <conio.h>
#include <dos.h>
#include <setjmp.h>

#include "\\software\\ucos-ii\\ix861\\os_cpu.h"
#include "os_cfg.h"
#include "\\software\\blocks\\pc\\source\\pc.h"
#include "\\software\\ucos-ii\\source\\ucos_ii.h"
```

### Listing 9.1, INCLUDES.H

## 9.03 OS\_CPU.H

**OS\_CPU.H** contains processor and implementation specific **#defines** constants, macros, and **typedefs**. **OS\_CPU.H** for the 80x86 port is shown in listing 9.2.

```
#ifndef OS_CPU_GLOBALS
#define OS_CPU_EXT
#else
#define OS_CPU_EXT extern
#endif

/*
*****
*                                     DATA TYPES
*                                     (Compiler Specific)
*****
*/

typedef unsigned char  BOOLEAN;
typedef unsigned char  INT8U;           /* Unsigned  8 bit quantity           */ (1)
typedef signed char    INT8S;           /* Signed   8 bit quantity             */
typedef unsigned int   INT16U;          /* Unsigned 16 bit quantity            */
typedef signed int     INT16S;          /* Signed  16 bit quantity             */
typedef unsigned long  INT32U;          /* Unsigned 32 bit quantity            */
typedef signed long    INT32S;          /* Signed  32 bit quantity             */
typedef float          FP32;            /* Single precision floating point     */
typedef double         FP64;            /* Double precision floating point     */

typedef unsigned int   OS_STK;          /* Each stack entry is 16-bit wide    */

#define BYTE           INT8S            /* Define data types for backward compatibility ... */
#define UBYTE          INT8U            /* ... to uC/OS V1.xx.  Not actually needed for ... */
#define WORD           INT16S           /* ... uC/OS-II.                          */
#define UWORD          INT16U
#define LONG            INT32S
#define ULONG          INT32U

/*
*****
*                                     Intel 80x86 (Real-Mode, Large Model)
*
* Method #1: Disable/Enable interrupts using simple instructions. After critical section, interrupts
* will be enabled even if they were disabled before entering the critical section. You MUST
* change the constant in OS_CPU_A.ASM, function OSIntCtxSw() from 10 to 8.
*
*/
```

```

* Method #2: Disable/Enable interrupts by preserving the state of interrupts. In other words, if
* interrupts were disabled before entering the critical section, they will be disabled when
* leaving the critical section. You MUST change the constant in OS_CPU_A.ASM, function
* OSIntCtxSw() from 8 to 10.
*****
*/
#define OS_CRITICAL_METHOD 2

#if OS_CRITICAL_METHOD == 1
#define OS_ENTER_CRITICAL() asm CLI /* Disable interrupts */ (2)
#define OS_EXIT_CRITICAL() asm STI /* Enable interrupts */
#endif

#if OS_CRITICAL_METHOD == 2
#define OS_ENTER_CRITICAL() asm {PUSHF; CLI} /* Disable interrupts */
#define OS_EXIT_CRITICAL() asm POPF /* Enable interrupts */
#endif

/*
*****
* Intel 80x86 (Real-Mode, Large Model) Miscellaneous
*****
*/

#define OS_STK_GROWTH 1 /* Stack grows from HIGH to LOW memory on 80x86 */ (3)

#define uCOS 0x80 /* Interrupt vector # used for context switch */ (4)

#define OS_TASK_SW() asm INT uCOS (5)

/*
*****
* GLOBAL VARIABLES
*****
*/

OS_CPU_EXT INT8U OSTickDOSCtr; /* Counter used to invoke DOS's tick handler every 'n' ticks */ (6)

```

## Listing 9.2, OS\_CPU.H

### 9.03.01 OS\_CPU.H, Data Types

Because different microprocessors have different word length, the port of  $\mu$  C/OS-II includes a series of type definitions that ensures portability L9.2(1). With the Borland C/C++ compiler, an **int** is 16-bit and a **long** is 32-bit. Also, for your convenience, I included floating-point data types even though  $\mu$  C/OS-II doesn't make use of floating-point.

A stack entry for the 80x86 processor running in in real-mode is 16-bit wide and thus, **OS\_STK** is declared accordingly for the Borland C/C++ compiler. All task stacks MUST be declared using **OS\_STK** as its data type.



### 9.03.02 *OS\_CPU.H, Critical Sections*

$\mu$  C/OS-II like all real-time kernels need to disable interrupts in order to access critical sections of code, and re-enable interrupts when done. This allows  $\mu$  C/OS-II to protect critical code from being entered simultaneously from either multiple tasks or ISRs. Because the Borland C/C++ compiler supports in-line assembly language, it's quite easy to specify the instructions to disable and enable interrupts.  $\mu$  C/OS-II defines the two *macros* to disable and enable interrupts: **OS\_ENTER\_CRITICAL( )** and **OS\_EXIT\_CRITICAL( )**, respectively. I actually provide you with two methods of disabling and enabling interrupts L9.2(2). The method used is established by the **#define** macro **OS\_CRITICAL\_METHOD** which can either be set to 1 or 2. For the tests, I chose method #2 but it's up to you to decide which one is best for your application.

#### Method #1:

The first and simplest way to implement these two macros is to invoke the processor instruction to disable interrupts (**CLI**) for **OS\_ENTER\_CRITICAL( )** and the enable interrupts instruction (**STI**) for **OS\_EXIT\_CRITICAL( )**. There is, however, a little problem with this scenario. If you called the  $\mu$  C/OS-II function with interrupts disabled then, upon return from  $\mu$  C/OS-II, interrupts would be enabled! If you had interrupts disabled, you may have wanted them to be disabled upon return from the  $\mu$  C/OS-II function. In this case, the above implementation would not be adequate. If you don't care in your application whether interrupts are enabled after calling a  $\mu$  C/OS-II service then, you should opt for this method because of performance. If you chose this method, you will need to change the constant in **OSIntCtxSw( )** from 10 to 8 (see **OS\_CPU\_A.ASM**)!

#### Method #2:

The second way to implement **OS\_ENTER\_CRITICAL( )** is to save the interrupt disable status onto the stack and then, disable interrupts. This is accomplished on the 80x86 by executing the **PUSHF** instruction followed by the **CLI** instruction. **OS\_EXIT\_CRITICAL( )** simply needs to execute a **POPF** instruction to restore the original contents of the processor's SW register. Using this scheme, if you called a  $\mu$  C/OS-II service with either interrupts enabled or disabled then, the status would be preserved across the call. A few words of caution however, if you call a  $\mu$  C/OS-II service with interrupts disabled, you are potentially extending the interrupt latency of your application. Also, your application will 'crash' if you have interrupts disabled before calling a service such as **OSTimeDly( )**. This will happen because the task will be suspended until time expires but, because interrupts are disabled, you would never service the tick interrupt! Obviously, all the PEND calls are also subject to this problem so, be careful. As a general rule, you should always call  $\mu$  C/OS-II services with interrupts enabled! If you want to preserve the interrupt disable status across  $\mu$  C/OS-II service calls then obviously this method is for you but be careful.

### 9.03.03 *OS\_CPU.H, Stack Growth*

The stack on an 80x86 processor grows from high-memory to low-memory which means that **OS\_STK\_GROWTH** must be set to 1 L9.2(3).

### 9.03.04 *OS\_CPU.H, OS\_TASK\_SW()*

In  $\mu$  C/OS-II, the stack frame for a ready task always looks as if an interrupt has just occurred and all processor registers were saved onto it. To switch context, **OS\_TASK\_SW( )** thus needs to simulate an interrupt L9.2(5). The 80x86 provides 256 software interrupts to accomplish this. The interrupt service routine (ISR) (also called the 'exception handler') MUST vector to the assembly language function **OSCtxSw( )** (see **OS\_CPU\_A.ASM**).

Because I tested the code on a PC, I decided to use interrupt number 128 (i.e. 0x80) because I found it to be available L9.2(4). Actually, the original PC used interrupts 0x80 through 0xF0 for the BASIC interpreter. Few if any PCs nowadays come with a BASIC interpreter built in so, it should be save to these vectors. Optionally, you can also use vectors 0x4B

to 0x5B, 0x5D to 0x66, or 0x68 to 0x6F. If you use this port on an embedded processor such as the 80186 processor you will most likely not be as restricted in your choice of vectors.

### ***9.03.05 OS\_CPU.H, Tick Rate***

The tick rate for an RTOS should generally be set between 10 and 100 Hz. It is always preferable (but not necessary) to set the tick rate to a 'round number'. Unfortunately, on the PC, the default tick rate is 18.20648 Hz which is not what I would call a nice 'round number'. For this port, I decided to change the tick rate of the PC from the standard 18.20648 Hz to 200 Hz (i.e. 5 mS between ticks). There are two reasons to do this. First, 200 Hz happens to be about 11 times faster than 18.20648 Hz. This will allow us to 'chain' into DOS once every 11 ticks. In DOS, the tick handler is responsible for some 'system' maintenance which is expected to happen every 54.93 mS. The second reason is to have 5.00 mS time resolution for time delays and timeouts. If you are running the example code on an 80386 PC, you may find that the overhead of the 200 Hz may be unacceptable. On a Pentium-II processor, however, 200 Hz is not likely to be a problem.

This brings us to the last statement in **OS\_CPU.H** which declares an 8-bit variable (**OSTickDOSCtr**) that will keep track of the number of times the ticker is called. Every 11<sup>th</sup> time, the DOS tick handler will be called L9.2(6). **OSTickDOSCtr** is used in **OS\_CPU\_A.ASM** and really only applies to a PC environment. You would most likely not use this scheme if you were to design an embedded system around a non-PC architecture because you would set the tick rate to the proper value in the first place.

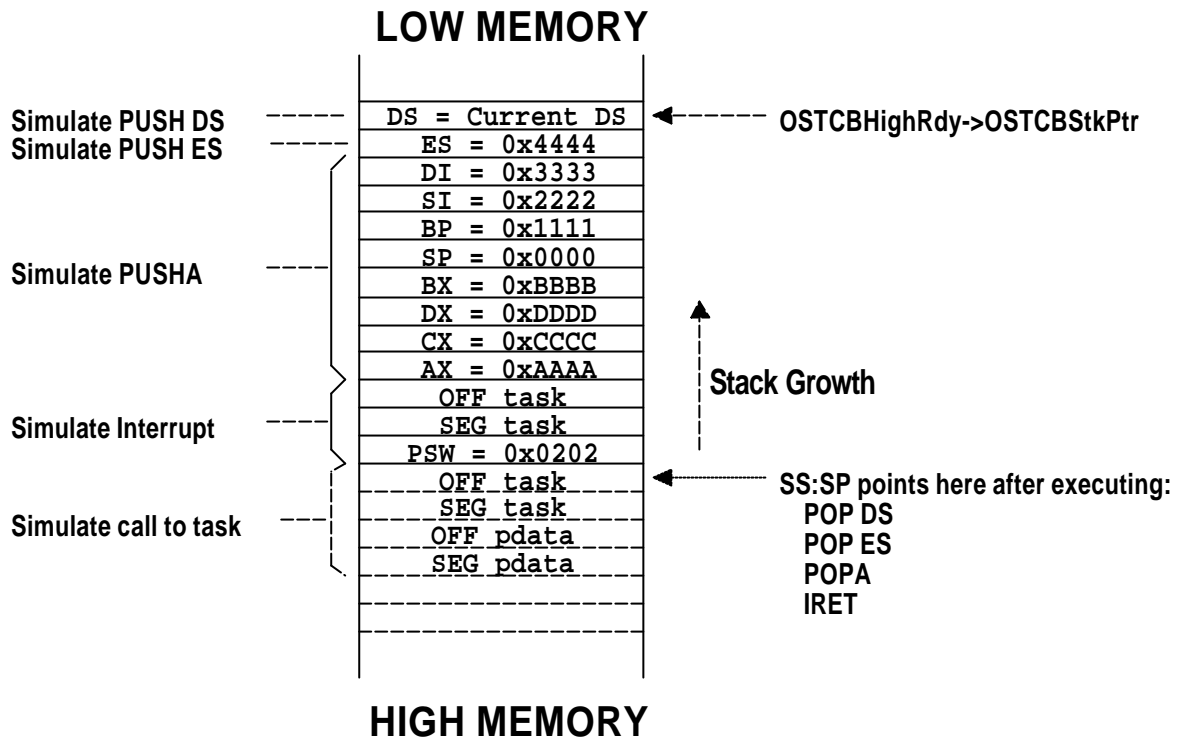
## ***9.04 OS\_CPU\_A.ASM***

A  $\mu$ C/OS-II port requires that you write four fairly simple assembly language functions:

```
OSStartHighRdy()  
OSCtxSw()  
OSIntCtxSw()  
OSTickISR()
```

### ***9.04.01 OS\_CPU\_A.ASM, OSStartHighRdy()***

This function is called by **OSStart()** to start the highest priority task ready-to-run. Before you can call **OSStart()**, however, you MUST have created at least one of your tasks (see **OSTaskCreate()** and **OSTaskCreateExt()**). **OSStartHighRdy()** assumes that **OSTCBHighRdy** points to the task control block of the task with the highest priority. Figure 9-3 shows the stack frame for an 80x86 real-mode task created by either **OSTaskCreate()** or **OSTaskCreateExt()**. As can be seen, **OSTCBHighRdy->OSTCBStkPtr** points to the task's top-of-stack.



**Figure 9-3, 80x86 Stack frame when task is created**

The code for **OSStartHighRdy ( )** is shown in listing 9.3.

```

_OSStartHighRdy  PROC FAR

    MOV     AX, SEG _OSTCBHighRdy      ; Reload DS
    MOV     DS, AX                    ;

    LES     BX, DWORD PTR DS:_OSTCBHighRdy ; SS:SP = OSTCBHighRdy->OSTCBStkPtr    (1)
    MOV     SS, ES:[BX+2]              ;
    MOV     SP, ES:[BX+0]              ;
;

    POP     DS                        ; Load task's context                      (2)
    POP     ES                        ;                                         (3)
    POPA                                         ;                                         (4)
;

    IRET                                ; Run task                               (5)

_OSStartHighRdy  ENDP

```

**Listing 9.3, OSStartHighRdy()**

To start the task, **OSStartHighRdy ( )** simply needs to retrieve and load the stack pointer from the task's **OS\_TCB** L9.3(1), execute a **POP DS** L9.3(2), **POP ES** L9.3(3), **POPA** L9.3(4) and **IRET**

L9.3(5) instructions. I decided to store the stack pointer at the beginning of the task control block (i.e. its **OS\_TCB**) to make it easier to access from assembly language.

Upon executing the **IRET** instruction, the task code is resumed and the stack pointer (i.e. SS:SP) is pointing at the return address of the task as if the task was called by a normal function. SS:SP+4 points to the argument **pdata** which is passed to the task..

### 9.04.02 OS\_CPU\_A.ASM, OSCtxSw()

A task level context switch is accomplished by executing a software interrupt instruction on the 80x86 processor. The interrupt service routine MUST vector to **OSCtxSw()**. The sequence of events that leads  $\mu$  C/OS-II to vector to **OSCtxSw()** is as follows. The current task calls a service provided by  $\mu$  C/OS-II which causes a higher priority task to be ready-to-run. At the end of the service call,  $\mu$  C/OS-II calls the function **OSSched()** which concludes that the current task is no longer the most important task to run. **OSSched()** loads the address of the highest priority task into **OSTCBHighRdy** and then executes the software interrupt instruction by invoking the macro **OS\_TASK\_SW()**. Note that the variable **OSTCBCur** already contains a pointer to the current task's Task Control Block, **OS\_TCB**. The code for **OSCtxSw()** is shown in listing 9.4. The numbers in parenthesis corresponds to the enumerated description that follows.

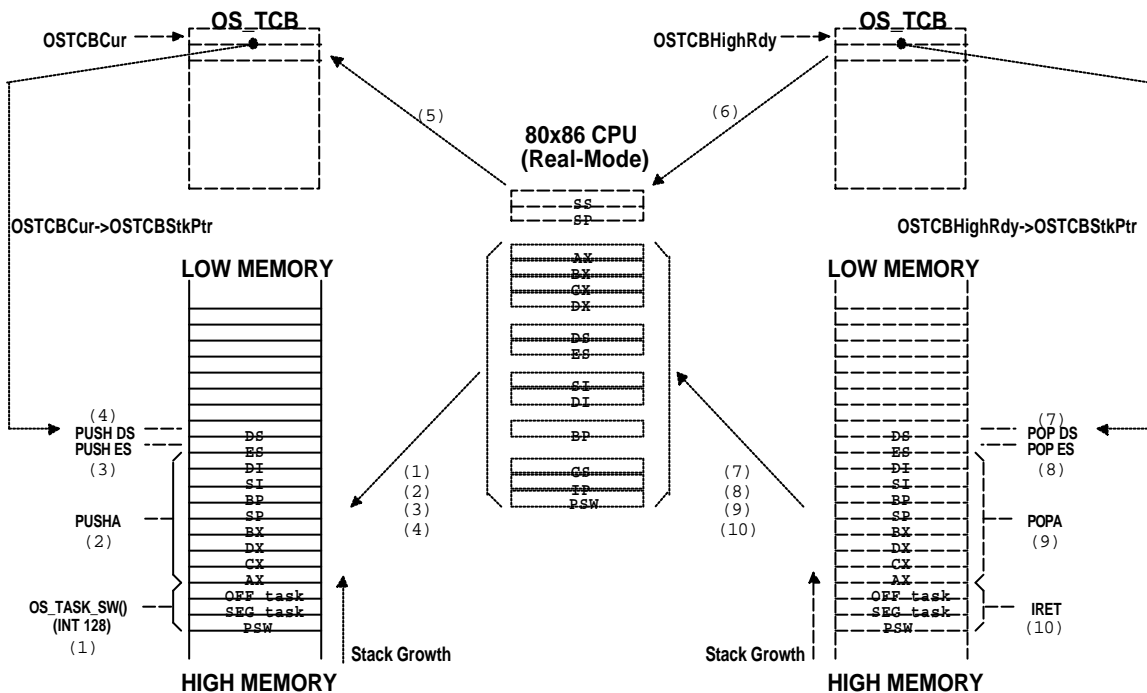
```

_OSCtxSw    PROC    FAR                                ; (1)
;
;           PUSHA                                ; Save current task's context (2)
;           PUSH    ES                            ; (3)
;           PUSH    DS                            ; (4)
;
;           MOV     AX, SEG _OSTCBCur              ; Reload DS in case it was altered
;           MOV     DS, AX                        ;
;
;           LES     BX, DWORD PTR DS:_OSTCBCur     ; OSTCBCur->OSTCBStkPtr = SS:SP (5)
;           MOV     ES:[BX+2], SS                  ;
;           MOV     ES:[BX+0], SP                  ;
;
;           CALL    FAR PTR _OSTaskSwHook          (6)
;
;           MOV     AX, WORD PTR DS:_OSTCBHighRdy+2 ; OSTCBCur = OSTCBHighRdy (7)
;           MOV     DX, WORD PTR DS:_OSTCBHighRdy  ;
;           MOV     WORD PTR DS:_OSTCBCur+2, AX    ;
;           MOV     WORD PTR DS:_OSTCBCur, DX      ;
;
;           MOV     AL, BYTE PTR DS:_OSPrioHighRdy ; OSPrioCur = OSPrioHighRdy (8)
;           MOV     BYTE PTR DS:_OSPrioCur, AL    ;
;
;           LES     BX, DWORD PTR DS:_OSTCBHighRdy ; SS:SP = OSTCBHighRdy->OSTCBStkPtr (9)
;           MOV     SS, ES:[BX+2]                  ;
;           MOV     SP, ES:[BX]                    ;
;
;           POP     DS                            ; Load new task's context (10)
;           POP     ES                            ; (11)
;           POPA                                ; (12)
;
;           IRET                                  ; Return to new task (13)
;
_OSCtxSw    ENDP

```

**Listing 9.4, OSCtxSw()**

Figure 9-4 shows the stack frames of the task being suspended and the task being resumed. On the 80x86 processor, the software interrupt instruction forces the SW register to be pushed onto the current task's stack followed by the return address (segment and offset) of the task that executed the **INT** instruction F9-4(1) & L9.4(1) (i.e. the task that invoked **OS\_TASK\_SW( )**). To save the rest of the task's context, the **PUSHA** F9-4(2) & L9.4(2), **PUSH ES** F9-4(3) & L9.4(3) and **PUSH DS** F9-4(4) & L9.4(4) instructions are executed. To finish saving the context of the task is being suspended, **OSCtxSw( )** saves the SS and SP registers in its **OS\_TCB** F9-4(5) & L9.4(5). It is important that the SS register be saved first. Intel guarantees that interrupts will be disabled for the next instruction. This means that saving of SS and SP are performed indivisibly.



**Figure 9-4, 80x86 Stack frames during a task level context switch**

The user definable task switch hook (**OSTaskSwHook( )**) is then called L9.4(6). Note that when **OSTaskSwHook( )** is called, **OSTCBCur** points to the current task's **OS\_TCB** while **OSTCBHighRdy** points to the new task's **OS\_TCB**. You can thus access each task's **OS\_TCB** from **OSTaskSwHook( )**. If you never intend to use the context switch hook, you can comment out the call which would save you a few clock cycles during the context switch.

Upon return from **OSTaskSwHook( )**, **OSTCBHighRdy** is then copied to **OSTCBCur** because the new task will now also be the current task L9.4(7). Also, **OSPrioHighRdy** is copied to **OSPrioCur** for the same reason L9.4(8). At this point, **OSCtxSw( )** can load the processor's registers with the new task's context. This is done by first retrieving the SS and SP registers from the new task's **OS\_TCB** F9-4(6) & L9.4(9). Again, it is important that the SS register be restored first. Intel guarantees that interrupts will be disabled for the next instruction. This means that restoring of SS and SP are performed indivisibly. The other registers are pulled from the stack by executing a **POP DS** F9-4(7) & L9.4(10), a **POP ES** F9-4(8) & L9.4(11), a **POPA** F9-4(9) & L9.4(12) and finally an **IRET** F9-4(10) & L9.4(13) instruction. The task code resumes once the **IRET** instruction completes.

You should note that interrupts are disabled during **OSCtxSw()** and also during execution of the user definable function **OSTaskSwHook()**.

### 9.04.03 OS\_CPU\_A.ASM, OSIntCtxSw()

**OSIntCtxSw()** is a function that is called by **OSIntExit()** to perform a context switch from an ISR (Interrupt Service Routine). Because **OSIntCtxSw()** is called from an ISR, it is assumed that all the processor registers are already properly saved onto the interrupted task's stack. In fact, there are more things on the stack frame than we need. **OSIntCtxSw()** will thus have to clean up the stack so that the interrupted task is left with just the proper stack frame content.

The code shown in listing 9.5 is identical to **OSCtxSw()** except for two things. First, there is no need to save the registers (i.e. use **PUSHA**, **PUSH ES** and **PUSH DS**) onto the stack because it is assumed that the beginning of the ISR has done that. Second, **OSIntCtxSw()** needs to adjust the stack pointer so that the stack frame only contains the task's context. To understand what is happening, refer also to figure 9-5 for the following description.

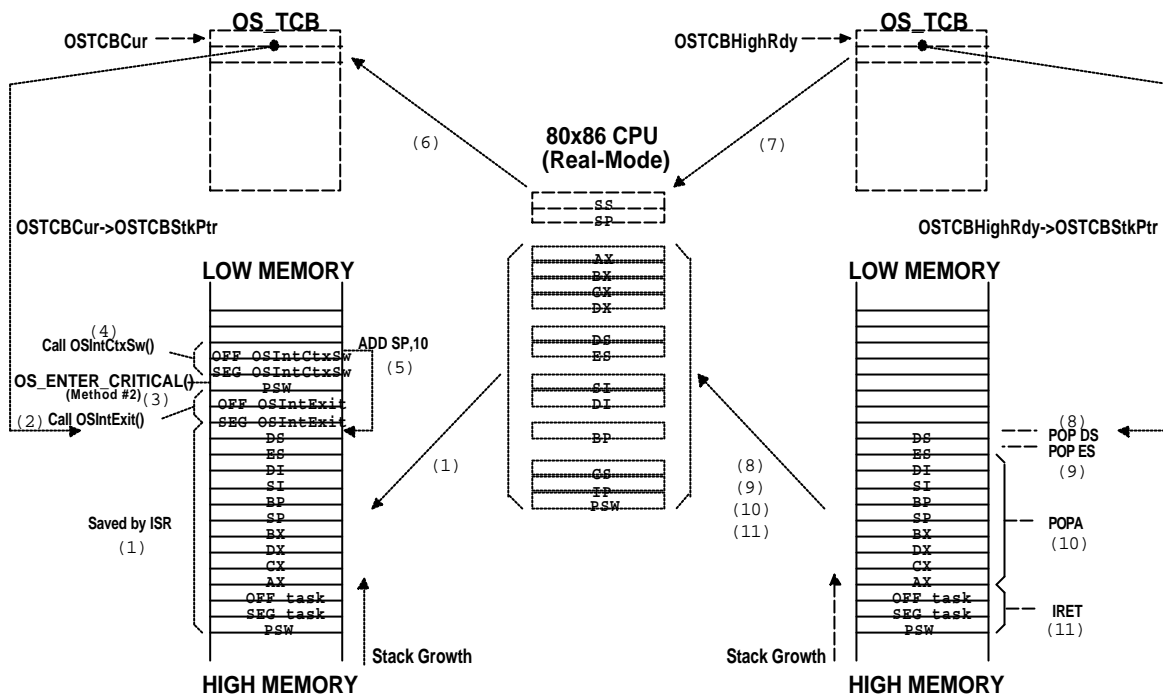
```

_OSCtxSw PROC    FAR
;
;                                     ; Ignore calls to OSIntExit and OSIntCtxSw
;      ADD     SP,8                    ; (Uncomment if OS_CRITICAL_METHOD is 1, see OS_CPU.H)  (1)
;      ADD     SP,10                  ; (Uncomment if OS_CRITICAL_METHOD is 2, see OS_CPU.H)
;
;      MOV     AX, SEG _OSTCBCur      ; Reload DS in case it was altered
;      MOV     DS, AX                ;
;
;      LES     BX, DWORD PTR DS:_OSTCBCur ; OSTCBCur->OSTCBStkPtr = SS:SP                (2)
;      MOV     ES:[BX+2], SS          ;
;      MOV     ES:[BX+0], SP          ;
;
;      CALL    FAR PTR _OSTaskSwHook  (3)
;
;      MOV     AX, WORD PTR DS:_OSTCBHighRdy+2 ; OSTCBCur = OSTCBHighRdy          (4)
;      MOV     DX, WORD PTR DS:_OSTCBHighRdy  ;
;      MOV     WORD PTR DS:_OSTCBCur+2, AX    ;
;      MOV     WORD PTR DS:_OSTCBCur, DX      ;
;
;      MOV     AL, BYTE PTR DS:_OSPrioHighRdy ; OSPrioCur = OSPrioHighRdy          (5)
;      MOV     BYTE PTR DS:_OSPrioCur, AL    ;
;
;      LES     BX, DWORD PTR DS:_OSTCBHighRdy ; SS:SP = OSTCBHighRdy->OSTCBStkPtr    (6)
;      MOV     SS, ES:[BX+2]              ;
;      MOV     SP, ES:[BX]                ;
;
;      POP     DS                        ; Load new task's context                    (7)
;      POP     ES                        ;                                           (8)
;      POPA                                ;                                           (9)
;
;      IRET                             ; Return to new task                        (10)
;
_OSCtxSw ENDP

```

### Listing 9.5, OSIntCtxSw()

Assuming that the processor recognizes an interrupt, the processor completes the current instruction and initiates an interrupt handling procedure. This consist of automatically pushing the processor status register followed by the return address of the interrupted task onto the stack.



**Figure 9-5, 80x86 Stack frames during an interrupt level context switch**

The CPU then vectors to the proper ISR.  $\mu$  C/OS-II requires that your ISR begins by saving the rest of the processor registers F9-5(1). Once the registers are saved,  $\mu$  C/OS-II requires that you either call **OSIntEnter()** or, that you increment the global variable **OSIntNesting** by one. At this point, the interrupted task's stack frame only contains the register contents of the interrupted task. The ISR can now start servicing the interrupting device and possibly, make a higher priority task ready. This would occur if the ISR sends a message to a task (by calling **OSMboxPost()** or **OSQPost()**), resume a task (by calling **OSTaskResume()**), invokes **OSTimeTick()** or **OSTimeDlyResume()**. Let us assume that a higher priority task is made ready to run.

$\mu$  C/OS-II requires that your ISR calls **OSIntExit()** when the ISR completes servicing the interrupting device. **OSIntExit()** basically tell  $\mu$  C/OS-II that it's time to return back to task level code. The call to **OSIntExit()** causes the return address of the caller to be pushed onto the interrupted task's stack F9-5(2).

**OSIntExit()** starts by disabling interrupts because it needs to execute critical code. Depending on how **OS\_ENTER\_CRITICAL()** is implemented (see section 9.03.02), the processor's status register could be pushed onto the interrupted task's stack F9-5(3). **OSIntExit()** notices that the interrupted task is no longer the task that needs to run because a higher priority task is now ready. In this case, the pointer **OSTCBHighRdy** is made to point to the new task's **OS\_TCB** and **OSIntExit()** calls **OSIntCtxSw()** to perform the context switch. Calling **OSIntCtxSw()** causes the return address to be pushed onto the interrupted task's stack F9-5(4).

Because we are switching context, we only want to leave item F9-5(1) on the stack and ignore items F9-5(2), F9-5(3), and F9-5(4). This is accomplished by adding a 'constant' to the stack pointer F9-5(5) & L9.5(1). When using Method #2 for **OS\_ENTER\_CRITICAL()**, this constant needs to be 10. If you decide to use Method #1, however, you will

need to change the constant to 8. The actual value of this constant depends on the compiler and compiler options. Specifically, a different compiler may allocate variables for **OSIntExit()**. Once the stack is adjusted, the new stack pointer can be saved into the **OS\_TCB** of the task being switched out F9-5(6) & L9.5(2). It is important that the **SS** register be saved first. Intel guarantees that interrupts will be disabled for the next instruction. This means that saving of **SS** and **SP** are performed indivisibly. **OSIntCtxSw()** is the only function in  $\mu$  C/OS-II (and also  $\mu$  C/OS) that is compiler specific and has generated more e-mail than any other aspect of  $\mu$  C/OS. If your port appears to crash after a few context switches then, you should suspect that the stack is not being properly adjusted in **OSIntCtxSw()**.

The user definable task switch hook (**OSTaskSwHook()**) is then called L9.5(3). Note that **OSTCBCur** points to the current task's **OS\_TCB** while **OSTCBHighRdy** points to the new task's **OS\_TCB**. You can thus access each task's **OS\_TCB** from **OSTaskSwHook()**. If you never intend to use the context switch hook, you can comment out the call which would save you a few clock cycles during the context switch.

Upon return from **OSTaskSwHook()**, **OSTCBHighRdy** is copied to **OSTCBCur** because the new task will now also be the current task L9.5(4). Also, **OSPrioHighRdy** is copied to **OSPrioCur** for the same reason L9.5(5). At this point, **OSCtxSw()** can load the processor's registers with the new task's context. This is done by first retrieving the **SS** and **SP** registers from the new task's **OS\_TCB** F9-5(7) & L9.5(6). Again, it is important that the **SS** register be restored first. Intel guarantees that interrupts will be disabled for the next instruction. This means that restoring of **SS** and **SP** are performed indivisibly. The other registers are pulled from the stack by executing a **POP DS** F9-5(8) & L9.5(7), a **POP ES** F9-5(9) & L9.5(8), a **POP A** F9-5(10) & L9.5(9) and finally an **IRET** F9-5(11) & L9.5(10) instruction. The task code resumes once the **IRET** instruction completes.

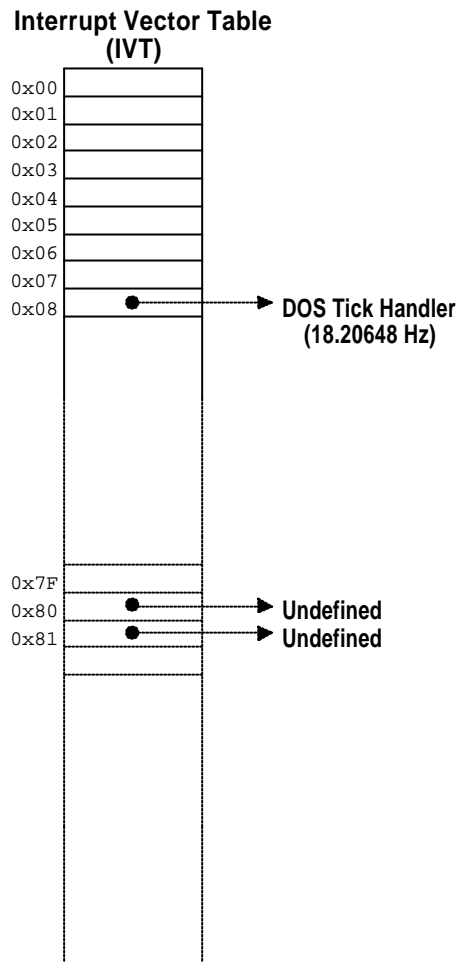
You should note that interrupts are disabled during **OSIntCtxSw()** and also during execution of the user definable function **OSTaskSwHook()**.

#### **9.04.04 OS\_CPU\_A.ASM, OSTickISR()**

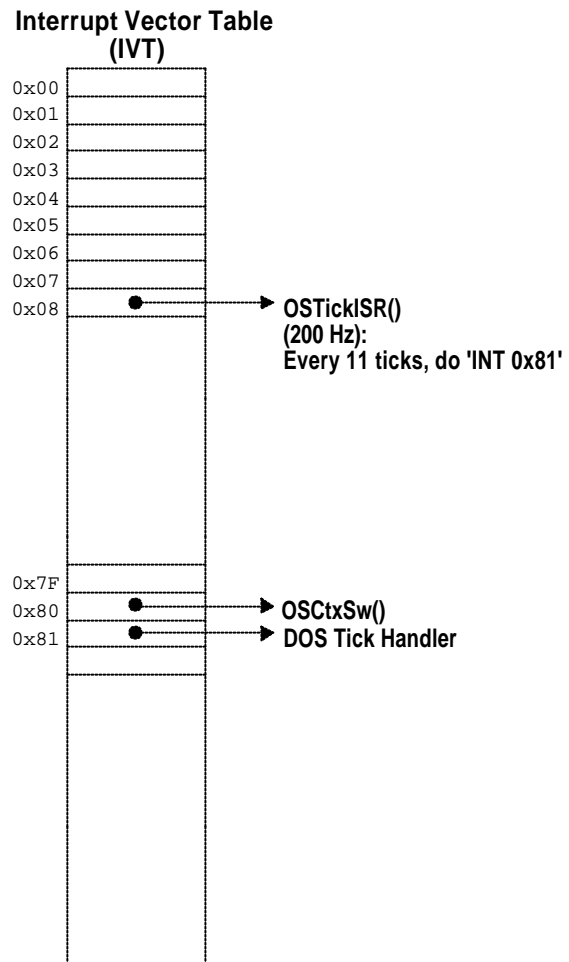
As mentioned in section 9.03.05, the tick rate of an RTOS should be set between 10 and 100 Hz. On the PC, the ticker occurs every 54.93 mS (18.20648 Hz) and is obtained by a hardware timer that interrupts the CPU. You should recall that I decided to reprogram the tick rate to 200 Hz. The ticker on the PC is assigned to vector 0x08 but  $\mu$  C/OS-II needs to have it 'redefined' so that it vectors to **OSTickISR()** instead. Because of this, the PC's tick handler is saved (see **PC.C, PC\_DOSSaveReturn()**) in vector 129 (0x81). To satisfy DOS, however, the PC's handler will be called every 54.93 mS (described shortly). Figure 9-6 shows the contents of the interrupt vector table (IVT) before and after installing  $\mu$  C/OS-II.



## Before (DOS only)



## After (OS-II installed)



**Figure 9-6, PC's Interrupt Vector Table (IVT)**

With  $\mu$  C/OS-II, it is very important that you enable ticker interrupts AFTER multitasking has started, i.e. after calling **OSstart()**. In the case of the PC, however, ticker interrupts are already occurring before you actually execute your  $\mu$  C/OS-II application. To prevent the ISR from invoking **OSTickISR()** until  $\mu$  C/OS-II is ready, you need to do the following:

```

PC_DOSSaveReturn() (see PC.C) which is called by main() needs to:
    Get the address of the interrupt handler for the DOS ticker;
    Relocate the DOS ticker at location 0x81;
main() needs to:
    Install the context switch vector (i.e. OSCtxSw()) at vector 0x80;
    Create at least one application task;
    Call OSStart() when ready to multitask;
The first task to execute needs to:
    Install OSTickISR() at vector 0x08;
    Change the tick rate from 18.20648 Hz to 200 Hz;

```

The tick handler on the PC is somewhat tricky so I decided to explain it using the pseudo code shown in listing 9.6. Like all  $\mu$ C/OS-II ISRs, all the registers need to be saved onto the current task's stack L9.6(1). Upon entering an ISR, you need to tell  $\mu$ C/OS-II that you are starting an ISR by either calling **OSIntEnter()** or, directly incrementing **OSIntNesting** L9.6(2). You can directly increment this variable because the 80x86 processor can perform this operation indivisibly. Next, the counter **OSTickDOSCtr** is decremented L9.6(3) and when it reaches 0, the DOS ticker handler is called L9.6(4). This happens every 54.93 mS. Ten times out of 11, however, a command is sent to the Priority Interrupt Controller (i.e. the PIC) to clear the interrupt L9.6(5). Note that there is no need to do this when the DOS ticker is called because the DOS ticker directly clears the interrupt source. Next, we call **OSTimeTick()** so that  $\mu$ C/OS-II can update all the tasks that are either waiting for time to expire or are pending for some event to occur but with a timeout L9.6(6). At the completion of all ISRs, **OSIntExit()** is called L9.6(7). If a higher priority task has been made ready by this ISR (or any other nested ISRs) and, this is the last nested ISR then **OSIntExit()** will NOT return to **OSTickISR()**! Instead, restoring the processor's context of the new task and issuing an **IRET** is done by **OSIntCtxSw()**. If the ISR is not the last nested ISR or the ISR did not cause a higher priority task to be ready then, **OSIntExit()** returns back to **OSTickISR()**. At this point, the processor registers are restored L9.6(8) and the ISR returns to the interrupted source by executing an **IRET** instruction L9.6(9).

```

void OSTickISR (void)
{
    Save processor registers;                                (1)
    OSIntNesting++;                                          (2)
    OSTickDOSCtr--;                                          (3)
    if (OSTickDOSCtr == 0) {
        Chain into DOS by executing an 'INT 81H' instruction; (4)
    } else {
        Send EOI command to PIC (Priority Interrupt Controller); (5)
    }
    OSTimeTick();                                           (6)
    OSIntExit();                                           (7)
    Restore processor registers;                             (8)
    Execute a return from interrupt instruction (IRET);      (9)
}

```

**Listing 9.6, Pseudo code for OSTickISR()**

This code for **OSTickISR()** is shown in listing 9.7 for reference.

```

_OSTickISR PROC FAR
;
;          PUSHA                ; Save interrupted task's context
;          PUSH    ES
;          PUSH    DS
;
;          MOV     AX, SEG _OSTickDOSCtr    ; Reload DS
;          MOV     DS, AX
;
;          INC     BYTE PTR _OSIntNesting  ; Notify uC/OS-II of ISR
;
;          DEC     BYTE PTR DS:_OSTickDOSCtr
;          CMP     BYTE PTR DS:_OSTickDOSCtr, 0
;          JNE     SHORT _OSTickISR1      ; Every 11 ticks (~199.99 Hz), chain into
DOS
;
;          MOV     BYTE PTR DS:_OSTickDOSCtr, 11
;          INT     081H                ; Chain into DOS's tick ISR
;          JMP     SHORT _OSTickISR2
;
_OSTickISR1:
;          MOV     AL, 20H                ; Move EOI code into AL.
;          MOV     DX, 20H                ; Address of 8259 PIC in DX.
;          OUT     DX, AL                ; Send EOI to PIC if not processing DOS timer.
;
_OSTickISR2:
;          CALL    FAR PTR _OSTimeTick    ; Process system tick
;
;          CALL    FAR PTR _OSIntExit     ; Notify uC/OS-II of end of ISR
;
;          POP     DS                    ; Restore interrupted task's context
;          POP     ES
;          POPA
;
;          IRET                          ; Return to interrupted task
;
_OSTickISR ENDP

```

## Listing 9.6, OSTickISR()

You can simplify **OSTickISR()** by not increasing the tick rate from 18.20648 Hz to 200 Hz. The pseudo code shown in listing 9.7 contains the steps that the tick ISR would need to take. The ISR still needs to save all the registers onto the current task's stack L9.7(1) and increment **OSIntNesting** L9.7(2). Next, the DOS ticker handler is called L9.7(3). Note that there is no need to clear the interrupt ourselves because this is handled by the DOS ticker. We then call **OSTimeTick()** so that  $\mu$ C/OS-II can update all the tasks that are either waiting for time to expire or are pending for some event to occur but with a timeout L9.7(4). When you are done servicing the ISR, you call **OSIntExit()** L9.7(5). Finally, the processor registers are restored L9.7(6) and the ISR returns to the interrupted source by executing an **IRET** instruction L9.7(7). Note that you MUST NOT change the tick rate by calling **PC\_SetTickRate()** if you are to use this version of the code. You will also have to change the configuration constant **OS\_TICKS\_PER\_SEC** (see **OS\_CFG.H**) from 200 to 18!

```

void OSTickISR (void)
{
    Save processor registers;                      (1)
    OSIntNesting++;                               (2)
    Chain into DOS by executing an 'INT 81H' instruction; (3)
    OSTimeTick();                                 (4)
    OSIntExit();                                  (5)
    Restore processor registers;                   (6)
    Execute a return from interrupt instruction (IRET); (7)
}

```

### Listing 9.7, Pseudo code for 18.2 Hz OSTickISR()

The new code for **OSTickISR( )** would look as shown in listing 9.8.

```

_OSTickISR  PROC    FAR
;
;          PUSHA                ; Save interrupted task's context
;          PUSH    ES
;          PUSH    DS
;
;          MOV     AX, SEG _OSIntNesting    ; Reload DS
;          MOV     DS, AX
;
;          INC     BYTE PTR _OSIntNesting  ; Notify uC/OS-II of ISR
;
;          INT     081H                  ; Chain into DOS's tick ISR
;
;          CALL    FAR PTR _OSTimeTick     ; Process system tick
;
;          CALL    FAR PTR _OSIntExit      ; Notify uC/OS-II of end of ISR
;
;          POP     DS                    ; Restore interrupted task's context
;          POP     ES
;          POPA
;
;          IRET                        ; Return to interrupted task
;
_OSTickISR  ENDP

```

### Listing 9.8, 18.2 Hz version of OSTickISR()

## 9.05 OS\_CPU\_C.C

A  $\mu$  C/OS-II port requires that you write six fairly simple C functions:

```

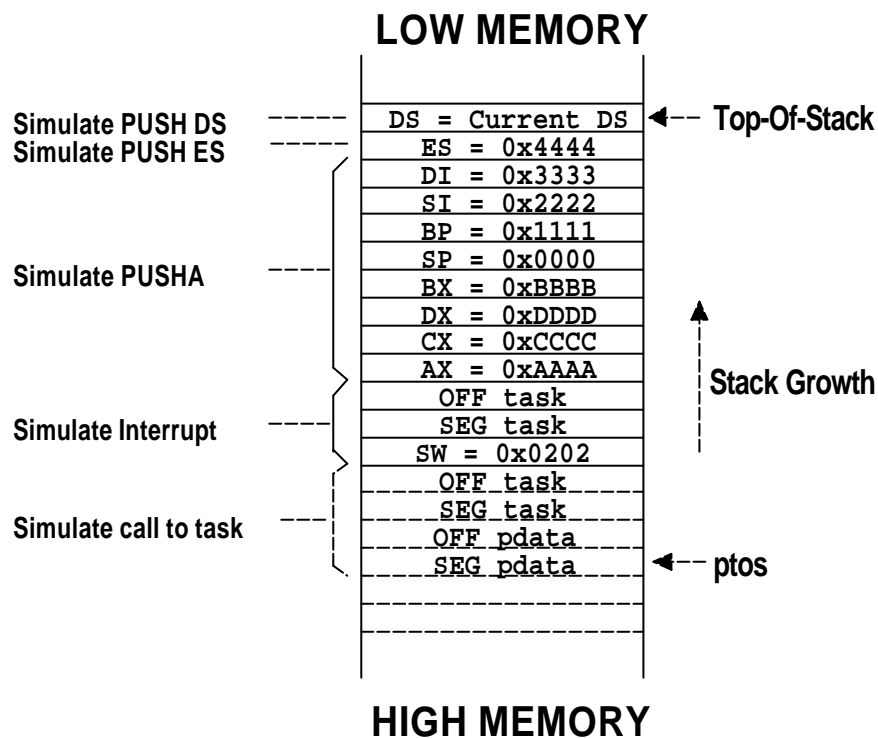
OSTaskStkInit()
OSTaskCreateHook()
OSTaskDelHook()
OSTaskSwHook()
OSTaskStatHook()
OSTimeTickHook()

```

The only function that is actually necessary is `OSTaskStkInit()`. The other five functions MUST be declared but don't need to contain any code inside them. I didn't put any code in these five functions in `OS_CPU_C.C` because I am assuming that they would be user defined. To that end, the `#define` constant `OS_CPU_HOOKS_EN` (see `OS_CFG.H`) is set to 0. To define the code in `OS_CPU_C.C`, you would need to set `OS_CPU_HOOKS_EN` to 1.

### 9.05.01 *OS\_CPU\_C.C, OSTaskStkInit()*

This function is called by `OSTaskCreate()` and `OSTaskCreateExt()` to initialize the stack frame of a task so that the stack looks as if an interrupt just occurred and all the processor registers were pushed onto that stack. Figure 9-7 shows what `OSTaskStkInit()` will put on the stack of the task being created. Note that the diagram doesn't show the stack frame of the code calling `OSTaskStkInit()` but instead, the stack frame of the task being created.



**Figure 9-7, Stack frame initialization with 'pdata' passed on the stack**

When you create a task, you specify to `OSTaskCreate()` or `OSTaskCreateExt()` the start address of the task (**task**), you pass it a pointer (**pdata**), the task's top-of-stack (**ptos**) and the task's priority (**prio**). `OSTaskCreateExt()` requires additional arguments but these are irrelevant in discussing `OSTaskStkInit()`. To properly initialize the stack frame, `OSTaskStkInit()` only requires the first three arguments just mentioned (i.e. **task**, **pdata** and **ptos**).

The code for **OSTaskStkInit()** is shown in listing 9.9.

```
void *OSTaskStkInit (void (*task)(void *pd), void *pdata, void *ptos, INT16U opt)
{
    INT16U *stk;

    opt      = opt;                /* 'opt' is not used, prevent warning */
    stk      = (INT16U *)ptos;     /* Load stack pointer (1) */
    *stk--   = (INT16U)FP_SEG(pdata); /* Simulate call to function with argument (2) */
    *stk--   = (INT16U)FP_OFF(pdata);
    *stk--   = (INT16U)FP_SEG(task); /* Place return address of function call (3) */
    *stk--   = (INT16U)FP_OFF(task);
    *stk--   = (INT16U)0x0202;      /* SW = Interrupts enabled (4) */
    *stk--   = (INT16U)FP_SEG(task); /* Put pointer to task on top of stack */
    *stk--   = (INT16U)FP_OFF(task);
    *stk--   = (INT16U)0xAAAA;      /* AX = 0xAAAA (5) */
    *stk--   = (INT16U)0xCCCC;      /* CX = 0xCCCC */
    *stk--   = (INT16U)0xDDDD;      /* DX = 0xDDDD */
    *stk--   = (INT16U)0xBBBB;      /* BX = 0BBBB */
    *stk--   = (INT16U)0x0000;      /* SP = 0x0000 */
    *stk--   = (INT16U)0x1111;      /* BP = 0x1111 */
    *stk--   = (INT16U)0x2222;      /* SI = 0x2222 */
    *stk--   = (INT16U)0x3333;      /* DI = 0x3333 */
    *stk--   = (INT16U)0x4444;      /* ES = 0x4444 */
    *stk     = _DS;                /* DS = Current value of DS (6) */
    return ((void *)stk);
}
```

### Listing 9.9, OSTaskStkInit()

**OSTaskStkInit()** creates and initializes a local pointer to 16-bit elements because stack entries are 16-bit wide on the 80x86 L9.9(1). Note that  $\mu$  C/OS-II requires that the pointer **ptos** points to an empty stack entry.

The Borland C/C++ compiler passes the argument **pdata** on the stack instead of registers (at least with the compiler options I selected). Because of this, **pdata** is placed on the stack frame with the OFFSET and SEGMENT in the order shown L9.9(2).

The address of your task is placed on the stack next L9.9(3). In theory, this should be the return address of your task. However, in  $\mu$  C/OS-II, a task must never return so, what is placed here is not really critical.

The Status Word (**SW**) along with the task address are placed on the stack L9.9(4) to simulate the behavior of the processor in response to an interrupt. The **SW** register is initialized to **0x0202**. This will allow the task to have interrupts enabled when it starts. You can in fact start all your tasks with interrupts disabled by forcing the **SW** to **0x0002** instead. There are no options in  $\mu$  C/OS-II to selectively enable interrupts upon startup for some tasks and disable interrupts upon task startup on others. In other words, either all tasks have interrupts disabled upon startup or all tasks have them disabled. You could, however, overcome this limitation by passing the desired interrupt startup state of a task by using **pdata**. If you chose to have interrupts disabled, each task will need to enable them when they execute. You will also have to modify **OSTaskIdle()** and **OSTaskStat()** to enable interrupts in those functions. If you don't, your application will crash! I would thus recommend that you leave the **SW** initialized to **0x0202** and have interrupts enabled when the task starts.

Next, the remaining registers are placed on the stack to simulate the **PUSHA**, **PUSH ES** and **PUSH DS** instructions which are assumed to be found at the beginning of every ISR L9.9(5). Note that the **AX**, **BX**, **CX**, **DX**, **SP**, **BP**, **SI** and **DI** registers are placed to satisfy the order of the **PUSHA** instruction. If you were to port this code to a 'plain' 8086

processor, you may want to simulate the **PUSHA** instruction or place the registers in a neater order. You should also note that each register has a unique value instead of all zeros. This can be useful for debugging. Also, the Borland compiler supports 'pseudo-registers' (i.e. the **\_DS** keyword notifies the compiler to obtain the value of the **DS** register) which in this case is used to copy the current value of the **DS** register to the simulated stack frame L9.9(6).

Once completed, **OSTaskStkInit()** returns the address of the new top-of-stack. **OSTaskCreate()** or **OSTaskCreateExt()** will take this address and save it in the task's **OS\_TCB**.

### **9.05.02    *OS\_CPU\_C.C, OSTaskCreateHook()***

As previously mentioned, **OS\_CPU\_C.C** does not define any code for this function.

### **9.05.03    *OS\_CPU\_C.C, OSTaskDelHook()***

As previously mentioned, **OS\_CPU\_C.C** does not define any code for this function.

### **9.05.04    *OS\_CPU\_C.C, OSTaskSwHook()***

As previously mentioned, **OS\_CPU\_C.C** does not define any code for this function. See Example #3 on how to use this function.

### **9.05.05    *OS\_CPU\_C.C, OSTaskStatHook()***

As previously mentioned, **OS\_CPU\_C.C** does not define any code for this function. See Example #3 for an example on how to use this function.

### **9.05.06    *OS\_CPU\_C.C, OSTimeTickHook()***

As previously mentioned, **OS\_CPU\_C.C** does not define any code for this function.

## 9.06 Memory requirements

Table 9.1 shows the amount of memory (both code and data space) used by  $\mu$ C/OS-II based on the value of configuration constants. *Data* in this case means RAM and *Code* means ROM if  $\mu$ C/OS-II is used in an embedded system. The spreadsheet is actually provided on the companion diskette (\SOFTWARE\uCOS-II\I86L\DOC\ROM-RAM.XLS). You will need Microsoft Excel for Office 97 (or higher) to use this file. The spreadsheet allows you to do 'what-if' scenarios based on the options you select.

Configuration Parameters	Value	CODE (Bytes)	DATA (Bytes)
OS_MAX_EVENTS	10		164
OS_MAX_MEM_PART	5		104
OS_MAX_QS	5		124
OS_MAX_TASKS	63		2925
OS_LOWEST_PRIO	63		264
OS_TASK_IDLE_STK_SIZE	512		1024
OS_TASK_STAT_EN	1	325	10
OS_TASK_STAT_STK_SIZE	512		1024
OS_CPU_HOOKS_EN	1		0
OS_MBOX_EN	1	600	(See OS_MAX_EVENTS)
OS_MEM_EN	1	725	(See OS_MAX_MEM_PART)
OS_Q_EN	1	1475	(See OS_MAX_QS)
OS_SEM_EN	1	475	(See OS_MAX_EVENTS)
OS_TASK_CHANGE_PRIO_EN	1	450	0
OS_TASK_CREATE_EN	1	225	1
OS_TASK_CREATE_EXT_EN	1	300	0
OS_TASK_DEL_EN	1	550	0
OS_TASK_SUSPEND_EN	1	525	0
$\Sigma$ /OS-II Internals		2700	35
Total Application Stacks	0		0
Total Application RAM	0		0
<b>TOTAL:</b>		<b>8350</b>	<b>5675</b>

**Table 9.1,  $\mu$ C/OS-II memory requirements for 80186.**

The number of bytes in the CODE column have been rounded up to the nearest 25 bytes. I used the Borland C/C++ compiler V3.1 and the options were set to generate the fastest code. The number of bytes shown are not meant to be accurate but are simply provided to give you a relative idea of how much code space each of the  $\mu$ C/OS-II group of services require. For example, if you don't need message queue services (i.e. **OS\_Q\_EN** set to 0) then you will save about 1475 bytes of code space. In this case,  $\mu$ C/OS-II would only use up 6875 bytes of code space.




The DATA column is not as straightforward. You should notice that the stacks for both the idle task and the statistics task have been set to 1024 (i.e. 1K) each. Based on your own requirements, this number may be higher or lower. As a minimum,  $\mu$ C/OS-II requires 35 bytes of RAM ( $\mu$ C/OS-II Internals) for internal data structures.

Table 9.2 shows how  $\mu$ C/OS-II can scale down the amount of memory required for smaller applications. In this case, I only allowed 16 tasks but with 64 priority levels (0 to 63). In this case, your application will not have access to:

- Message mailbox services (**OS\_MBOX\_EN** set to 0)
- Memory partition services (**OS\_MEM\_EN** set to 0)
- Changing task priorities (**OS\_TASK\_CHANGE\_PRIO\_EN** set to 0)
- The old task creation (**OSTaskCreate( )**) function (**OS\_TASK\_CREATE\_EN** set to 0)
- Deleting task (**OS\_TASK\_DEL\_EN** set to 0)
- Suspending and Resuming tasks (**OS\_TASK\_SUSPEND\_EN** set to 0)

Notice that the CODE space reduced by about 3K and the DATA space reduced by over 2200 bytes! Most of the DATA savings come from the reduced number of **OS\_TCB**s needed because only 16 tasks are available. For the 80x86 large model port, each **OS\_TCB** eats up 45 bytes of RAM.

Configuration Parameters	Value	CODE (Bytes)	DATA (Bytes)
OS_MAX_EVENTS	10		164
OS_MAX_MEM_PART	5		0
OS_MAX_QS	5		124
OS_MAX_TASKS	16		792
OS_LOWEST_PRIO	63		264
OS_TASK_IDLE_STK_SIZE	512		1024
OS_TASK_STAT_EN	1	325	10
OS_TASK_STAT_STK_SIZE	512		1024
OS_CPU_HOOKS_EN	1		0
OS_MBOX_EN	0	0	(See OS_MAX_EVENTS)
OS_MEM_EN	0	0	(See OS_MAX_MEM_PART)
OS_Q_EN	1	1475	(See OS_MAX_QS)
OS_SEM_EN	1	475	(See OS_MAX_EVENTS)
OS_TASK_CHANGE_PRIO_EN	0	0	0
OS_TASK_CREATE_EN	0	0	1
OS_TASK_CREATE_EXT_EN	1	300	0
OS_TASK_DEL_EN	0	0	0
OS_TASK_SUSPEND_EN	0	0	0
 /OS-II Internals		2700	35
Total Application Stacks	0		0
Total Application RAM	0		0
<b>TOTAL:</b>		<b>5275</b>	<b>3438</b>

**Table 9.2, A scaled down  $\mu$ C/OS-II configuration.**

## 9.07 *Execution times*

Tables 9.3 and 9.4 show the execution time for most  $\mu$ C/OS-II functions. The values were obtained by having the compiler generate assembly language code for the 80186 processor with the C source interleaved as comments. The assembly code was then passed through the Microsoft MASM 6.11 assembler with the option set so that the number of cycles for each instruction gets included. I then added the number of instructions (the **I** column) and clock cycles (the **C** column) for the code to obtain three values: the maximum amount of time interrupts are disabled for the service, the minimum execution time of the service and its maximum. As you can imagine, this is a very tedious job but worth the effort. Giving you this information allows you to see the 'cost' impact of each function in terms of execution time. Obviously, this information has very little use unless you are using a 80186 processor except for the fact that it gives you an idea of the relative cost for each function.

The number of clock cycles were divided by 33 (i.e. I assumed a 33 MHz clock) to obtain the execution time of the service in  $\mu$ S (i.e. the  **$\mu$ S** column). For the minimum and maximum times, I always assumed that the intended function of the service was performed successfully. I further assumed that the processor was able to run at the full bus speed (i.e. without any wait states). On average, I determined that the 80186 requires 10 clock cycles per instruction!

For the 80186, maximum interrupt disable time is 33.3  $\mu$ S (or 1100 clock cycles).

N/A means that the execution time for the function was not determined because I didn't believe they were critical.

I provided the column listing the number of instructions because you can determine the execution time of the functions for other x86 processors if you have an idea of the number of cycles per instruction. For example, you could assume that a 80486 executes (on average) an instruction every 2 clock cycle (5 times faster than a 80186). Also, if your 80486 was running at 66 MHz instead of 33 MHz (2 times faster) then you could take the execution times listed in the tables and divide them all by 10.

Service	Interrupts Disabled			Minimum			Maximum		
	I	C	礎	I	C	礎	I	C	礎
<b>Miscellaneous</b>									
OSInit()	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OSSchedLock()	4	34	1.0	7	87	2.6	7	87	2.6
OSSchedUnlock()	57	567	17.2	13	130	3.9	73	782	23.7
OSStart()	0	0	0.0	35	278	8.4	35	278	8.4
OSStatInit()	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OSVersion()	0	0	0.0	2	19	0.6	2	19	0.6
<b>Interrupt Management</b>									
OSIntEnter()	4	42	1.3	4	42	1.3	4	42	1.3
OSIntExit()	56	558	16.9	27	207	6.3	57	574	17.4
OSTickISR()	30	310	9.4	948	10803	327.4	2304	20620	624.8
<b>Message Mailboxes</b>									
OSMboxAccept()	15	161	4.9	13	257	7.8	13	257	7.8
OSMboxCreate()	15	148	4.5	115	939	28.5	115	939	28.5
OSMboxPend()	68	567	17.2	28	317	9.6	184	1912	57.9
OSMboxPost()	84	747	22.6	24	305	9.2	152	1484	45.0
OSMboxQuery()	120	988	29.9	128	1257	38.1	128	1257	38.1
<b>Memory Partition Management</b>									
OSMemCreate()	21	181	5.5	72	766	23.2	72	766	23.2
OSMemGet()	19	247	7.5	18	172	5.2	33	350	10.6
OSMemPut()	23	282	8.5	12	161	4.9	29	321	9.7
OSMemQuery()	40	400	12.1	45	450	13.6	45	450	13.6
<b>Message Queues</b>									
OSQAccept()	34	387	11.7	25	269	8.2	44	479	14.5
OSQCreate()	14	150	4.5	154	1291	39.1	154	1291	39.1
OSQFlush()	18	202	6.1	25	253	7.7	25	253	7.7
OSQPend()	64	620	18.8	45	495	15.0	186	1938	58.7
OSQPost()	98	873	26.5	51	547	16.6	155	1493	45.2
OSQPostFront()	87	788	23.9	44	412	12.5	153	1483	44.9
OSQQuery()	128	1100	33.3	137	1171	35.5	137	1171	35.5
<b>Semaphore Management</b>									
OSSemAccept()	10	113	3.4	16	161	4.9	16	161	4.9
OSSemCreate()	14	140	4.2	98	768	23.3	98	768	23.3
OSSemPend()	58	567	17.2	17	184	5.6	164	1690	51.2
OSSemPost()	87	776	23.5	18	198	6.0	151	1469	44.5
OSSemQuery()	110	882	26.7	116	931	28.2	116	931	28.2

**Table 9.3, Execution times of  $\mu$  C/OS-II services on 33 MHz 80186.**

Service	Interrupts Disabled			Minimum			Maximum		
	I	C	礎	I	C	礎	I	C	礎
<b>Task Management</b>									
OSTaskChangePrio()	63	567	17.2	178	981	29.7	166	1532	46.4
OSTaskCreate()	57	567	17.2	217	2388	72.4	266	2939	89.1
OSTaskCreateExt()	57	567	17.2	284	3157	95.7	284	3157	95.7
OSTaskDel()	62	620	18.8	116	1206	36.5	165	1757	53.2
OSTaskDelReq()	23	199	6.0	39	330	10.0	39	330	10.0
OSTaskResume()	27	242	7.3	48	430	13.0	97	981	29.7
OSTaskStkChk()	31	316	9.6	62	599	18.2	62	599	18.2
OSTaskSuspend()	37	352	10.7	63	579	17.5	112	1130	34.2
OSTaskQuery()	84	1025	31.1	95	1122	34.0	95	1122	34.0
<b>Time Management</b>									
OSTimeDly()	57	567	17.2	81	844	25.6	85	871	26.4
OSTimeDlyHMSM()	57	567	17.2	216	2184	66.2	220	2211	67.0
OSTimeDlyResume()	57	567	17.2	23	181	5.5	98	989	30.0
OSTimeGet()	7	57	1.7	14	117	3.5	14	117	3.5
OSTimeSet()	7	61	1.8	11	99	3.0	11	99	3.0
OSTimeTick()	30	310	9.4	900	10257	310.8	1908	19707	597.2
<b>User Defined Functions</b>									
OSTaskCreateHook()	0	0	0.0	4	38	1.2	4	38	1.2
OSTaskDelHook()	0	0	0.0	4	38	1.2	4	38	1.2
OSTaskStatHook()	0	0	0.0	1	16	0.5	1	16	0.5
OSTaskSwHook()	0	0	0.0	1	16	0.5	1	16	0.5
OSTimeTickHook()	0	0	0.0	1	16	0.5	1	16	0.5

**Table 9.4, Execution times of  $\mu$  C/OS-II services on 33 MHz 80186.**

Below is a list of assumptions about how the minimum, maximum and interrupt disable times were determined and the conditions that lead to these values.

#### **OSSchedUnlock() :**

*Minimum* assumes that **OSLockNesting** is decremented to 0 but there are no higher priority tasks ready to run and thus **OSSchedUnlock()** returns to the caller.

*Maximum* also decrements **OSLockNesting** to 0 but this time, a higher priority task is ready to run. This means that a context switch would occur.

#### **OSIntExit() :**

*Minimum* assumes that **OSIntNesting** is decremented to 0 but there are no higher priority tasks ready to run and thus **OSIntExit()** returns to the interrupted task.

*Maximum* also decrements **OSIntNesting** to 0 but this time, the ISR has made a higher priority task is ready to run. This means that **OSIntExit()** will not return to the interrupted task but instead, to the higher priority task that is ready to run.

#### **OSTickISR() :**

For this function, I assumed that your application can have the maximum number of tasks allowed by  $\mu$  C/OS-II (64 tasks total).

*Minimum* assumes that none of the 64 tasks are either waiting for time to expire or for a timeout on an event.

*Maximum* assumed that ALL 63 tasks (the idle task is never waiting) are waiting for time to expire. 625  $\mu$  S may seem like a lot of time but, if you consider that all the tasks are waiting for time to expire then the CPU has

nothing else to do anyway! On average, though, you can assume that **OSTickISR( )** would take about 500  $\mu$  S (i.e. 5% overhead if your tick interrupts occurs every 10 mS).

#### **OSMboxPend( ) :**

*Minimum* assumes that a message is available at the mailbox.

*Maximum* occurs when a message is not available so, the task will have to wait. In this case, a context switch occurs. The maximum time is as seen by the calling task. In other words, this is the time it takes to look at the mailbox, determine that there is no message, call the scheduler, context switch to the new task, context switch back from whatever task was running, determine that a timeout occurred and returning to the caller.

#### **OSMboxPost( ) :**

*Minimum* assumes that the mailbox is empty and that no task is waiting on the mailbox to contain a message.

*Maximum* occurs when one or more tasks are waiting on the mailbox for a message. In this case, the message is given to the highest priority task waiting and a context switch is performed to resume that task. Again, the maximum time is as seen by the calling task. In other words, this is the time it takes to wake up the waiting task, pass it the message, call the scheduler, context switch to the task, context switch back from whatever task was running, determine that a timeout occurred and returning to the caller.

#### **OSMemGet( ) :**

*Minimum* assumes that a memory block is not available.

*Maximum* assumes that a memory block is available and is returned to the caller.

#### **OSMemPut( ) :**

*Minimum* assumes that you are returning a memory block to an already full partition.

*Maximum* assumes that you are returning the memory block to the partition.

#### **OSQPend( ) :**

*Minimum* assumes that a message is available at the queue.

*Maximum* occurs when a message is not available so, the task will have to wait. In this case, a context switch occurs. The maximum time is as seen by the calling task. In other words, this is the time it takes to look at the queue, determine that there is no message, call the scheduler, context switch to the new task, context switch back from whatever task was running, determine that a timeout occurred and returning to the caller.

### **OSQPost ( ) :**

*Minimum* assumes that the queue is empty and that no task is waiting on the queue to contain a message.

*Maximum* occurs when one or more tasks are waiting on the queue for a message. In this case, the message is given to the highest priority task waiting and a context switch is performed to resume that task. Again, the maximum time is as seen by the calling task. In other words, this is the time it takes to wake up the waiting task, pass it the message, call the scheduler, context switch to the task, context switch back from whatever task was running, determine that a timeout occurred and returning to the caller.

### **OSQPostFront ( ) :**

This function performs virtually the same processing as **OSQPost ( )**.

### **OSSemPend ( ) :**

*Minimum* assumes that the semaphore is available (i.e. has a count higher than 0).

*Maximum* occurs when the semaphore is not available so, the task will have to wait. In this case, a context switch occurs. As usual, the maximum time is as seen by the calling task. This is the time it takes to look at the semaphore value, determine that it's 0, call the scheduler, context switch to the new task, context switch back from whatever task was running, determine that a timeout occurred and returning to the caller.

### **OSSemPost ( ) :**

*Minimum* assumes that there are no tasks waiting on the semaphore.

*Maximum* occurs when one or more tasks are waiting for the semaphore. In this case, the highest priority task waiting is readied and a context switch is performed to resume that task. Again, the maximum time is as seen by the calling task. This is the time it takes to wake up the waiting task, call the scheduler, context switch to the task, context switch back from whatever task was running, determine that a timeout occurred and returning to the caller.

### **OSTaskChangePrio ( ) :**

*Minimum* assumes that you are changing the priority of a task that will not have a priority higher than the current task.

*Maximum* assumes that you are changing the priority of a task that will have a higher priority than the current task. In this case, a context switch will occur.

### **OSTaskCreate ( ) :**

*Minimum* assumes that **OSTaskCreate ( )** will not create a higher priority task and thus no context switch is involved.

*Maximum* assumes that **OSTaskCreate ( )** is creating a higher priority task and thus a context switch will result.

In both cases, the execution times assumed that **OSTaskCreateHook ( )** didn't do anything.

### **OSTaskCreateExt ( ) :**

*Minimum* assumes that **OSTaskCreateExt ( )** will not need to initialize the stack with zeros in order to do stack checking.

*Maximum* assumes that **OSTaskCreateExt ( )** will have to initialize the stack of the task. However, the execution time greatly depends on the number of elements to initialize. I determined that it takes 100 clock cycles (3  $\mu$  S) to clear each element. A 1000 byte stack would require: 1000 bytes divided by 2 bytes/element (16-bit wide stack) times 3  $\mu$  S per element or, 1500  $\mu$  S. Note that interrupts are enabled while the stack is being cleared to allow your application can respond to interrupts.

In both cases, the execution times assumed that **OSTaskCreateHook ( )** didn't do anything.

### **OSTaskDel ( ) :**

*Minimum* assumes that the task being deleted is not the current task.

*Maximum* assumes that the task being deleted is the current task. In this case, a context switch will occur.

#### **OSTaskDelReq( ):**

Both *minimum* and *maximum* assume that the call will return indication that the task is deleted. This function is so short that it doesn't make much difference anyway.

#### **OSTaskResume( ):**

*Minimum* assumes that a task is being resumed but this task has a lower priority than the current task. In this case, a context switch will not occur.

*Maximum* assumes that the task being resumed will be ready-to-run and will have a higher priority than the current task. In this case, a context switch will occur.

#### **OSTaskStkChk( ):**

*Minimum* assumes that **OSTaskStkChk( )** is checking a 'full' stack. Obviously, this is hardly possible since the task being checked would most likely have crashed. However, this does establish the absolute minimum execution time, however unlikely.

*Maximum* also assumes that **OSTaskStkChk( )** is checking a 'full' stack but you need to add the amount of time it takes to check each 'zero' stack element. I was able to determine that each element takes 80 clock cycles (2.4  $\mu$  S) to check. A 1000 byte stack would thus require: 1000 bytes divided by 2 bytes/element (16-bit wide stack) times 2.4  $\mu$  S per element or, 1200  $\mu$  S. Total execution time would thus be 1218  $\mu$  s. Note that interrupts are enabled while the stack is being checked.

#### **OSTaskSuspend( ):**

*Minimum* assumes that the task being suspended is not the current task.

*Maximum* assumes that the current task is being suspended and a context switch will occur.

#### **OSTaskQuery( ):**

*Minimum* and *maximum* are the same and it is assumed that all the options are included so that an **OS\_TCB** contains all the fields. In this case, an **OS\_TCB** for the large model port requires 45 bytes.

#### **OSTimeDly( ):**

Both the *minimum* and *maximum* assume that the time delay will be greater than 0 tick. In this case, a context switch always occurs.

*Minimum* is the case where the bit in **OSRdyGrp** doesn't need to be cleared.

#### **OSTimeDlyHMSM( ):**

Both the *minimum* and *maximum* assume that the time delay will be greater than 0. In this case, a context switch will occur. Furthermore, the time specified must result in a delay of less than 65536 ticks. In other words, if a tick interrupt occurs every 10 mS (100 Hz) then the maximum value that you can specify is 10 minutes, 55 seconds and 350 mS in order for the execution times shown to be valid. Obviously, you can specify longer delays using this function call.

#### **OSTimeDlyResume( ):**

*Minimum* assumes that the delayed task is made ready to run but, this task has a lower priority than the current task. In this case,  $\mu$  C/OS-II will not perform a context switch.

*Maximum* assumes that the delayed task is made ready to run and this task has a higher priority than the current task. This, of course, results in a context switch.

#### **OSTimeTick( ):**

This function is almost identical to **OSTickISR( )** except that **OSTickISR( )** accounted for **OSIntEnter( )** and **OSIntExit( )**. I assumed that your application can have the maximum number of tasks allowed by  $\mu$  C/OS-II (64 tasks total).

*Minimum* assumes that none of the 64 tasks are either waiting for time to expire or for a timeout on an event.

*Maximum* assumed that ALL 63 tasks (the idle task is never waiting) are waiting for time to expire. 600  $\mu$  S may seem like a lot of time but, if you consider that all the tasks are waiting for time to expire then the CPU has nothing else to do anyway! On average, though, you can assume that **OSTimeTick( )** would take about 450  $\mu$  S (i.e. 4.5% overhead if your tick interrupt occurs every 10 mS).



Service	Interrupts Disabled			Minimum			Maximum		
	I	C	礧	I	C	礧	I	C	礧
OSVersion()	0	0	.0	2	19	.6	2	19	.6
OSStart()	0	0	.0	35	278	8.4	35	278	8.4
OSSchedLock()	4	34	1.0	7	87	2.6	7	87	2.6
OSIntEnter()	4	42	1.3	4	42	1.3	4	42	1.3
OSTimeGet()	7	57	1.7	14	117	3.5	14	117	3.5
OSTimeSet()	7	61	1.8	11	99	3.0	11	99	3.0
OSSemAccept()	10	113	3.4	16	161	4.9	16	161	4.9
OSSemCreate()	14	140	4.2	98	768	23.3	98	768	23.3
OSMboxCreate()	15	148	4.5	115	939	28.5	115	939	28.5
OSQCreate()	14	150	4.5	154	1291	39.1	154	1291	39.1
OSMboxAccept()	15	161	4.9	13	257	7.8	13	257	7.8
OSMemCreate()	21	181	5.5	72	766	23.2	72	766	23.2
OSTaskDelReq()	23	199	6.0	39	330	10.0	39	330	10.0
OSQFlush()	18	202	6.1	25	253	7.7	25	253	7.7
OSTaskResume()	27	242	7.3	48	430	13.0	97	981	29.7
OSMemGet()	19	247	7.5	18	172	5.2	33	350	10.6
OSMemPut()	23	282	8.5	12	161	4.9	29	321	9.7
OSTimeTick()	30	310	9.4	900	10257	310.8	1908	19707	597.2
OSTickISR()	30	310	9.4	948	10803	327.4	2304	20620	624.8
OSTaskStkChk()	31	316	9.6	62	599	18.2	62	599	18.2
OSTaskSuspend()	37	352	10.7	63	579	17.5	112	1130	34.2
OSQAccept()	34	387	11.7	25	269	8.2	44	479	14.5
OSMemQuery()	40	400	12.1	45	450	13.6	45	450	13.6
OSIntExit()	56	558	16.9	27	207	6.3	57	574	17.4
OSSchedUnlock()	57	567	17.2	13	130	3.9	73	782	23.7
OSTimeDly()	57	567	17.2	81	844	25.6	85	871	26.4
OSTimeDlyResume()	57	567	17.2	23	181	5.5	98	989	30.0
OSTaskChangePrio()	63	567	17.2	178	981	29.7	166	1532	46.4
OSSemPend()	58	567	17.2	17	184	5.6	164	1690	51.2
OSMboxPend()	68	567	17.2	28	317	9.6	184	1912	57.9
OSTimeDlyHMSM()	57	567	17.2	216	2184	66.2	220	2211	67.0
OSTaskCreate()	57	567	17.2	217	2388	72.4	266	2939	89.1
OSTaskCreateExt()	57	567	17.2	235	2606	95.7	284	3157	95.7
OSTaskDel()	62	620	18.8	116	1206	36.5	165	1757	53.2
OSQPend()	64	620	18.8	45	495	15.0	186	1938	58.7
OSMboxPost()	84	747	22.6	24	305	9.2	152	1484	45.0
OSSemPost()	87	776	23.5	18	198	6.0	151	1469	44.5
OSQPostFront()	87	788	23.9	44	412	12.5	153	1483	44.9
OSQPost()	98	873	26.5	51	547	16.6	155	1493	45.2
OSSemQuery()	110	882	26.7	116	931	28.2	116	931	28.2
OSMboxQuery()	120	988	29.9	128	1257	38.1	128	1257	38.1
OSTaskQuery()	84	1025	31.1	95	1122	34.0	95	1122	34.0
OSQQuery()	128	1100	33.3	137	1171	35.5	137	1171	35.5
OSInit()	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OSStatInit()	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

**Table 9.5, Execution times sorted by interrupt disable time.**

Service	Interrupts Disabled			Minimum			Maximum		
	I	C	礎	I	C	礎	I	C	礎
OSVersion()	0	0	.0	2	19	.6	2	19	.6
OSIntEnter()	4	42	1.3	4	42	1.3	4	42	1.3
OSSchedLock()	4	34	1.0	7	87	2.6	7	87	2.6
OSTimeSet()	7	61	1.8	11	99	3.0	11	99	3.0
OSTimeGet()	7	57	1.7	14	117	3.5	14	117	3.5
OSSemAccept()	10	113	3.4	16	161	4.9	16	161	4.9
OSQFlush()	18	202	6.1	25	253	7.7	25	253	7.7
OSMboxAccept()	15	161	4.9	13	257	7.8	13	257	7.8
OSStart()	0	0	.0	35	278	8.4	35	278	8.4
OSMemPut()	23	282	8.5	12	161	4.9	29	321	9.7
OSTaskDelReq()	23	199	6.0	39	330	10.0	39	330	10.0
OSMemGet()	19	247	7.5	18	172	5.2	33	350	10.6
OSMemQuery()	40	400	12.1	45	450	13.6	45	450	13.6
OSQAccept()	34	387	11.7	25	269	8.2	44	479	14.5
OSIntExit()	56	558	16.9	27	207	6.3	57	574	17.4
OSTaskStkChk()	31	316	9.6	62	599	18.2	62	599	18.2
OSMemCreate()	21	181	5.5	72	766	23.2	72	766	23.2
OSSemCreate()	14	140	4.2	98	768	23.3	98	768	23.3
OSSchedUnlock()	57	567	17.2	13	130	3.9	73	782	23.7
OSTimeDly()	57	567	17.2	81	844	25.6	85	871	26.4
OSSemQuery()	110	882	26.7	116	931	28.2	116	931	28.2
OSMboxCreate()	15	148	4.5	115	939	28.5	115	939	28.5
OSTaskResume()	27	242	7.3	48	430	13.0	97	981	29.7
OSTimeDlyResume()	57	567	17.2	23	181	5.5	98	989	30.0
OSTaskQuery()	84	1025	31.1	95	1122	34.0	95	1122	34.0
OSTaskSuspend()	37	352	10.7	63	579	17.5	112	1130	34.2
OSQQuery()	128	1100	33.3	137	1171	35.5	137	1171	35.5
OSMboxQuery()	120	988	29.9	128	1257	38.1	128	1257	38.1
OSQCreate()	14	150	4.5	154	1291	39.1	154	1291	39.1
OSSemPost()	87	776	23.5	18	198	6.0	151	1469	44.5
OSQPostFront()	87	788	23.9	44	412	12.5	153	1483	44.9
OSMboxPost()	84	747	22.6	24	305	9.2	152	1484	45.0
OSQPost()	98	873	26.5	51	547	16.6	155	1493	45.2
OSTaskChangePrio()	63	567	17.2	178	981	29.7	166	1532	46.4
OSSemPend()	58	567	17.2	17	184	5.6	164	1690	51.2
OSTaskDel()	62	620	18.8	116	1206	36.5	165	1757	53.2
OSMboxPend()	68	567	17.2	28	317	9.6	184	1912	57.9
OSQPend()	64	620	18.8	45	495	15.0	186	1938	58.7
OSTimeDlyHMSM()	57	567	17.2	216	2184	66.2	220	2211	67.0
OSTaskCreate()	57	567	17.2	217	2388	72.4	266	2939	89.1
OSTaskCreateExt()	57	567	17.2	235	2606	95.7	284	3157	95.7
OSTimeTick()	30	310	9.4	900	10257	310.8	1908	19707	597.2
OSTickISR()	30	310	9.4	948	10803	327.4	2304	20620	624.8
OSInit()	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OSStatInit()	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

**Table 9.6, Execution times sorted by maximum execution time.**

## Chapter 10

# Upgrading from $\mu$ C/OS to $\mu$ C/OS-II

This chapter describes what you need to do to migrate a port done for  $\mu$  C/OS to run on  $\mu$  C/OS-II. If you have gone through the effort of porting  $\mu$  C/OS to a processor then the amount of work to get this port to work with  $\mu$  C/OS-II should be minimal. In most cases, you should be able to do this in about an hour. If you are familiar with the  $\mu$  C/OS port then, you may want to go to the summary in section 10.05.

### 10.00 Directories and Files

The first thing you will notice in that the directory structure for  $\mu$  C/OS-II is similar to  $\mu$  C/OS except that the main directory is called `\SOFTWARE\uCOS-II` instead of `\SOFTWARE\uCOS`, respectively.

All  $\mu$  C/OS-II ports should be placed under the `\SOFTWARE\uCOS-II` directory on your hard drive. The source code for each microprocessor or microcontroller port *MUST* be found in either two or three files: `OS_CPU.H`, `OS_CPU.C` and optionally, `OS_CPU.A.SM`. The assembly language file is optional because some compilers will allow you to have in-line assembly language and thus, you can place the needed assembly language code directly in `OS_CPU.C`.

The processor specific code (i.e. the port) for  $\mu$  C/OS was placed in files having the processor name as part of the file names. For example, the Intel 80x86 real-mode, large model had files called: `Ix86L.H`, `Ix86L.C.C`, and `Ix86L.A.SM`. Table 10.1 shows the correspondence between the new file and directory names and the old ones.

<code>\SOFTWARE\uCOS\Ix86L</code>	<code>\SOFTWARE\uCOS-II\Ix86L</code>
<code>Ix86L.H</code>	<code>OS_CPU.H</code>
<code>Ix86L.A.SM</code>	<code>OS_CPU.A.SM</code>
<code>Ix86L.C.C</code>	<code>OS_CPU.C.C</code>

Table 10.1, Renaming files for  $\mu$  C/OS-II

As a starting point, all you have to do is copy the old file names (from the  $\mu$  C/OS directory) to the new names in the equivalent  $\mu$  C/OS-II directory. It will be easier to modify these files than to create them from scratch. Table 10.2 shows a few more examples of  $\mu$  C/OS port file translations.

<code>\SOFTWARE\uCOS\I80251</code>	<code>\SOFTWARE\uCOS-II\I80251</code>
<code>I80251.H</code>	<code>OS_CPU.H</code>
<code>I80251.C</code>	<code>OS_CPU.C.C</code>
<code>\SOFTWARE\uCOS\M680x0</code>	<code>\SOFTWARE\uCOS-II\M680x0</code>
<code>M680x0.H</code>	<code>OS_CPU.H</code>
<code>M680x0.C</code>	<code>OS_CPU.C.C</code>

<code>\SOFTWARE\uCOS\M68HC11</code>	<code>\SOFTWARE\uCOS-II\M68HC11</code>
<code>M68HC11.H</code>	<code>OS_CPU.H</code>
<code>M68HC11.C</code>	<code>OS_CPU_C.C</code>
<code>\SOFTWARE\uCOS\Z80</code>	<code>\SOFTWARE\uCOS-II\Z80</code>
<code>Z80.H</code>	<code>OS_CPU.H</code>
<code>Z80_A.ASM</code>	<code>OS_CPU_A.ASM</code>
<code>Z80_C.C</code>	<code>OS_CPU_C.C</code>

**Table 10.2, Renaming files from  $\mu$  C/OS to  $\mu$ C/OS-II**

### 10.01 *INCLUDES.H*

You will need to modify the **INCLUDES.H** file of your application. For example, the  $\mu$  C/OS INCLUDES.H file for the Intel 80x86 real mode, large model looks as shown in listing 10.1. You will need to edit this file and change:

- a) the directory name **UCOS** to **uCOS-II**
- b) the file name **IX86L.H** to **OS\_CPU.H**
- c) the file name **UCOS.H** to **uCOS-II.H**

The new file should thus look as shown in listing 10.2.

```

/*
*****
*
*           INCLUDES.H
*
*****
*/

#include    <STDIO.H>
#include    <STRING.H>
#include    <CTYPE.H>
#include    <STDLIB.H>
#include    <CONIO.H>
#include    <DOS.H>

#include    "\SOFTWARE\UCOS\IX86L\IX86L.H"
#include    "OS_CFG.H"
#include    "\SOFTWARE\UCOS\SOURCE\UCOS.H"

```

**Listing 10.1,  $\mu$  C/OS INCLUDES.H**

```

/*
*****
*
*           INCLUDES.H
*
*****
*/

#include    <STDIO.H>

```

```
#include <STRING.H>
#include <CTYPE.H>
#include <STDLIB.H>
#include <CONIO.H>
#include <DOS.H>

#include " \SOFTWARE\uCOS-II\IX86L\OS_CPU.H"
#include "OS_CFG.H"
#include " \SOFTWARE\uCOS-II\SOURCE\uCOS_II.H"
```

## Listing 10.2, $\mu$ C/OS-II INCLUDES.H

### 10.02 *OS\_CPU.H*

**OS\_CPU.H** contains processor and implementation specific **#defines** constants, macros, and **typedefs**.

#### 10.02.01 *OS\_CPU.H, Compiler specific data types*

To satisfy  $\mu$  C/OS-II, you will need to create six new data types: **INT8U**, **INT8S**, **INT16U**, **INT16S**, **INT32U** and **INT32S**. These corresponds to unsigned and signed 8, 16 and 32 bit integers, respectively. In  $\mu$  C/OS, I had declared the equivalent data types: **UBYTE**, **BYTE**, **UWORD**, **WORD**, **ULONG** and **LONG**. All you have to do is copy the  $\mu$  C/OS data types and change **UBYTE** to **INT8U**, **BYTE** to **INT8S**, **UWORD** to **INT16U** ...as shown in listing 10.3.

```
/* uC/OS data types: */
typedef unsigned char UBYTE; /* Unsigned 8 bit quantity */
typedef signed char BYTE; /* Signed 8 bit quantity */
typedef unsigned int UWORD; /* Unsigned 16 bit quantity */
typedef signed int WORD; /* Signed 16 bit quantity */
typedef unsigned long ULONG; /* Unsigned 32 bit quantity */
typedef signed long LONG; /* Signed 32 bit quantity */

/* uC/OS-II data types */
typedef unsigned char INT8U; /* Unsigned 8 bit quantity */
typedef signed char INT8S; /* Signed 8 bit quantity */
typedef unsigned int INT16U; /* Unsigned 16 bit quantity */
typedef signed int INT16S; /* Signed 16 bit quantity */
typedef unsigned long INT32U; /* Unsigned 32 bit quantity */
typedef signed long INT32S; /* Signed 32 bit quantity */
```

## Listing 10.3, $\mu$ C/OS to $\mu$ C/OS-II data types

In  $\mu$  C/OS, a task stack was declared as being of type **OS\_STK\_TYPE**. A stack, in  $\mu$  C/OS-II, must be declared as being of type **OS\_STK**. To prevent you from editing all your application files, you could simply create the two data types in **OS\_CPU.H** as shown in listing 10.4 (Intel 80x86 given as an example).

```
#define OS_STK_TYPE UBYTE /* Satisfy uC/OS */
#define OS_STK INT8U /* Satisfy uC/OS-II */
```

## Listing 10.4, $\mu$ C/OS and $\mu$ C/OS-II task stack data types

### 10.02.02 *OS\_CPU.H, OS\_ENTER\_CRITICAL() and OS\_EXIT\_CRITICAL()*

$\mu$  C/OS-II (as did  $\mu$  C/OS) defines two *macro*s to disable and enable interrupts: **OS\_ENTER\_CRITICAL()** and **OS\_EXIT\_CRITICAL()**, respectively. You shouldn't have to change these macros when migrating from  $\mu$  C/OS to  $\mu$  C/OS-II.

### 10.02.03 *OS\_CPU.H, OS\_STK\_GROWTH*

The stack on most microprocessors and microcontrollers grows from high-memory to low-memory. There are, however, some processors that work the other way around.  $\mu$  C/OS-II has been designed to be able to handle either flavor. This is accomplished by specifying to  $\mu$  C/OS-II which way the stack grows through the configuration constant **OS\_STK\_GROWTH** as shown below:

Set **OS\_STK\_GROWTH** to 0 for Low to High memory stack growth.

Set **OS\_STK\_GROWTH** to 1 for High to Low memory stack growth.

These are new **#define** constants from  $\mu$  C/OS so you will need to include them in **OS\_CPU.H**.

### 10.02.04 *OS\_CPU.H, OS\_TASK\_SW()*

**OS\_TASK\_SW()** is a macro that is invoked when  $\mu$  C/OS-II switches from a low-priority task to the highest-priority task. **OS\_TASK\_SW()** is always called from task level code. This macro doesn't need to be changed from  $\mu$  C/OS to  $\mu$  C/OS-II.

### 10.02.05 *OS\_CPU.H, OS\_FAR*

**OS\_FAR** was used in  $\mu$  C/OS because of the Intel 80x86 architecture. This **#define** has been removed in  $\mu$  C/OS-II because it made the code less portable. It turns out that if you specify the large model (for the Intel 80x86) then all memory references assumed the '**far**' attribute anyway.

All tasks in  $\mu$  C/OS were declared as shown in listing 10.5. You can either edit all the files that made references to **OS\_FAR** or simply create a macro in **OS\_CPU.H** to equate **OS\_FAR** to nothing in order to satisfy  $\mu$  C/OS-II.

```
void OS_FAR task (void *pdata)
{
    pdata = pdata;
    while (1) {
        .
        .
    }
}
```

**Listing 10.5, Declaration of a task in  $\mu$  C/OS**

## 10.03 *OS\_CPU\_A.ASM*

A  $\mu$  C/OS and  $\mu$  C/OS-II port requires that you write four fairly simple assembly language functions:

```

OSStartHighRdy()
OSCtSw()
OSIntCtSw()
OSTickISR()

```

### 10.03.01 OS\_CPU\_A.ASM, OSStartHighRdy()

In  $\mu$  C/OS-II, **OSStartHighRdy()** MUST call **OSTaskSwHook()**. **OSTaskSwHook()** did not exist. **OSStartHighRdy()** need to call **OSTaskSwHook()** before you load the stack pointer of the highest priority task. Also, **OSStartHighRdy()** needs to set **OSRunning** to **1** immediately after calling **OSTaskSwHook()**. Listing 10.6 shows the pseudo-code of **OSStartHighRdy()**.  $\mu$  C/OS only had the last three steps.

```

OSStartHighRdy:
    Call OSTaskSwHook();
    Set OSRunning to 1;
    Load the processor stack pointer with OSTCBHighRdy->OSTCBStkPtr;
    POP all the processor registers from the stack;
    Execute a Return from Interrupt instruction;

```

**Listing 10.6, Pseudo-code for OSStartHighRdy()**

### 10.03.02 OS\_CPU\_A.ASM, OSCtSw()

Two things have been added in  $\mu$  C/OS-II during a context switch. First, you MUST call **OSTaskSwHook()** immediately after saving the current task's stack pointer into the current task's TCB. Second, you MUST set **OSPrioCur** to **OSPrioHighRdy** BEFORE you load the new task's stack pointer.

Listing 10.7 shows the pseudo-code of **OSCtSw()**.  $\mu$  C/OS-II adds steps L10.7(1) and L10.7(2).

```

OSCtSw:
    PUSH processor registers onto the current task's stack;
    Save the stack pointer at OSTCBCur->OSTCBStkPtr;
    Call OSTaskSwHook();                                     (1)
    OSTCBCur = OSTCBHighRdy;
    OSPrioCur = OSPrioHighRdy;                             (2)
    Load the processor stack pointer with OSTCBHighRdy->OSTCBStkPtr;
    POP all the processor registers from the stack;
    Execute a Return from Interrupt instruction;

```

**Listing 10.7, Pseudo-code for OSCtSw()**

### 10.03.03 OS\_CPU\_A.ASM, OSIntCtSw()

Like **OSCtSw()**, two things have been added in **OSIntCtSw()** for  $\mu$  C/OS-II. First, you MUST call **OSTaskSwHook()** immediately after saving the current task's stack pointer into the current task's TCB. Second, you MUST set **OSPrioCur** to **OSPrioHighRdy** BEFORE you load the new task's stack pointer.

Listing 10.8 shows the pseudo-code of **OSIntCtSw()**.  $\mu$  C/OS-II adds steps L10.8(1) and L10.8(2).

```

OSCtxSw:
    Save the stack pointer at OSTCBCur->OSTCBStkPtr;
    Call OSTaskSwHook();                                     (1)
    OSTCBCur = OSTCBHighRdy;
    OSPrioCur = OSPrioHighRdy;                             (2)
    Load the processor stack pointer with OSTCBHighRdy->OSTCBStkPtr;
    POP all the processor registers from the stack;
    Execute a Return from Interrupt instruction;

```

### Listing 10.8, Pseudo-code for OSIntCtxSw()

#### 10.03.04 *OS\_CPU\_A.ASM, OSTickISR()*

The code for this function in  $\mu$  C/OS-II is identical to  $\mu$  C/OS and thus shouldn't be altered.

#### 10.04 *OS\_CPU\_C.C*

A  $\mu$  C/OS-II port requires that you write six fairly simple C functions:

```

OSTaskStkInit()
OSTaskCreateHook()
OSTaskDelHook()
OSTaskSwHook()
OSTaskStatHook()
OSTimeTickHook()

```

The only function that is actually necessary is **OSTaskStkInit()**. The other five functions MUST be declared but don't need to contain any code inside them.

#### 10.04.01 *OS\_CPU\_C.C, OSTaskStkInit()*

In  $\mu$  C/OS, **OSTaskCreate()** was considered a processor specific function. It turned out that only a portion of **OSTaskCreate()** was actually processor specific. This portion has been extracted out of **OSTaskCreate()** and placed in a new function called **OSTaskStkInit()**.

**OSTaskStkInit()** is only responsible for setting up the task's stack to look as if an interrupt just occurred and all the processor registers were pushed onto the task's stack. To give you an example, listing 10.9 shows the  $\mu$  C/OS code for **OSTaskCreate()** for the Intel 80x86 real-mode, large model. Listing 10.10 shows the code for **OSTaskStkInit()** for the same processor but for  $\mu$  C/OS-II. As you can see by comparing the two listings, lines L10.9(2) through L10.9(18) have basically been extracted from **OSTaskCreate()** and placed in **OSTaskStkInit()**. In other words, everything after **OS\_EXIT\_CRITICAL()** L10.9(1) and calling **OSTCBInit()** L10.9(19) has been moved to **OSTaskStkInit()**.

You will notice that the code for  $\mu$  C/OS-II uses the new data types (see section 10.02.01, *OS\_CPU.H, Compiler specific data types*). Also, instead of initializing all the processor registers to **0x0000**, I decided to initialize them with a value that would make debugging a little easier. You should note that the initial value of a register when a task is created is not critical.



```

UBYTE OSTaskCreate(void (*task)(void *pd), void *pdata, void *pstk, UBYTE p)
{
    UWORD OS_FAR *stk;
    UBYTE      err;

    OS_ENTER_CRITICAL();
    if (OSTCBPrioTbl[p] == (OS_TCB *)0) {
        OSTCBPrioTbl[p] = (OS_TCB *)1;
        OS_EXIT_CRITICAL();
        stk      = (UWORD OS_FAR *)pstk;
        *--stk = (UWORD)FP_OFF(pdata);
        *--stk = (UWORD)FP_SEG(task);
        *--stk = (UWORD)FP_OFF(task);
        *--stk = (UWORD)0x0202;
        *--stk = (UWORD)FP_SEG(task);
        *--stk = (UWORD)FP_OFF(task);
        *--stk = (UWORD)0x0000;
        *--stk = (UWORD)0x0000;
        *--stk = (UWORD)0x0000;
        *--stk = (UWORD)0x0000;
        *--stk = (UWORD)0x0000;
        *--stk = (UWORD)0x0000;
        *--stk = (UWORD)0x0000;
        *--stk = (UWORD)0x0000;
        *--stk = (UWORD)0x0000;
        *--stk = _DS;
        err      = OSTCBInit(p, (void far *)stk);
        if (err == OS_NO_ERR) {
            if (OSRunning) {
                OSSched();
            }
        } else {
            OSTCBPrioTbl[p] = (OS_TCB *)0;
        }
        return (err);
    } else {
        OS_EXIT_CRITICAL();
        return (OS_PRIO_EXIST);
    }
}

```

**Listing 10.9, OSTaskCreate() for  $\mu$ C/OS**

```

void *OSTaskStkInit (void (*task)(void *pd), void *pdata, void *ptos, INT16U opt)
{
    INT16U *stk;

    opt      = opt;
    stk      = (INT16U *)ptos;
    *stk-- = (INT16U)FP_SEG(pdata);
    *stk-- = (INT16U)FP_OFF(pdata);
    *stk-- = (INT16U)FP_SEG(task);
    *stk-- = (INT16U)FP_OFF(task);
    *stk-- = (INT16U)0x0202;
    *stk-- = (INT16U)FP_SEG(task);
    *stk-- = (INT16U)FP_OFF(task);
    *stk-- = (INT16U)0xAAAA;
    *stk-- = (INT16U)0xCCCC;
    *stk-- = (INT16U)0xDDDD;
    *stk-- = (INT16U)0xBBBB;
    *stk-- = (INT16U)0x0000;
    *stk-- = (INT16U)0x1111;
    *stk-- = (INT16U)0x2222;
    *stk-- = (INT16U)0x3333;
    *stk-- = (INT16U)0x4444;
    *stk    = _DS;
    return ((void *)stk);
}

```

**Listing 10.10, OSTaskStkInit() for  $\mu$ C/OS-II**

#### **10.04.02 OS\_CPU\_C.C, OSTaskCreateHook()**

**OSTaskCreateHook()** is a function that did not exist in  $\mu$  C/OS. If you are simply migrating from  $\mu$  C/OS to  $\mu$  C/OS-II then you can simply declare an empty function as shown in listing 10.11. You should note that if I didn't assign **ptcb** to **ptcb** then some compilers would generate a warning indicating that the argument **ptcb** is not used.

```

#ifdef OS_CPU_HOOKS_EN
OSTaskCreateHook(OS_TCB *ptcb)
{
    ptcb = ptcb;
}
#endif

```

**Listing 10.11, OSTaskCreateHook() for  $\mu$  C/OS-II**

You should also wrap the function declaration with the conditional compilation directive. The code for **OSTaskCreateHook()** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**. This allows the user of your port to redefine all the hook functions in a different file.

### ***10.04.03 OS\_CPU\_C.C, OSTaskDelHook()***

**OSTaskDelHook( )** is a function that did not exist in  $\mu$  C/OS. Again, if you are migrating from  $\mu$  C/OS to  $\mu$  C/OS-II then you can simply declare an empty function as shown in listing 10.12. You should note that if I didn't assign **ptcb** to **ptcb** then some compilers would generate a warning indicating that the argument **ptcb** is not used.

```
#if OS_CPU_HOOKS_EN
OSTaskDelHook(OS_TCB *ptcb)
{
    ptcb = ptcb;
}
#endif
```

#### **Listing 10.12, OSTaskDelHook() for $\mu$ C/OS-II**

You should also wrap the function declaration with the conditional compilation directive. The code for **OSTaskDelHook( )** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**. This allows the user of your port to redefine all the hook functions in a different file.

### ***10.04.04 OS\_CPU\_C.C, OSTaskSwHook()***

**OSTaskSwHook( )** is also function that did not exist in  $\mu$  C/OS. If you are migrating from  $\mu$  C/OS to  $\mu$  C/OS-II then you can simply declare an empty function as shown in listing 10.13.

```
#if OS_CPU_HOOKS_EN
OSTaskSwHook(void)
{
}
#endif
```

#### **Listing 10.13, OSTaskSwHook() for $\mu$ C/OS-II**

You should also wrap the function declaration with the conditional compilation directive. The code for **OSTaskSwHook( )** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**.

### ***10.04.05 OS\_CPU\_C.C, OSTaskStatHook()***

**OSTaskStatHook( )** is also function that did not exist in  $\mu$  C/OS. You can simply declare an empty function as shown in listing 10.14.

```
#if OS_CPU_HOOKS_EN
OSTaskStatHook(void)
{
}
#endif
```

### **Listing 10.14, OSTaskStatHook() for $\mu$ C/OS-II**

You should also wrap the function declaration with the conditional compilation directive. The code for **OSTaskStatHook()** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**.

#### ***10.04.06 OS\_CPU\_C.C, OStimeTickHook()***

**OStimeTickHook()** is also function that did not exist in  $\mu$  C/OS. You can simply declare an empty function as shown in listing 10.15.

```
#if OS_CPU_HOOKS_EN
OStimeTickHook(void)
{
}
#endif
```

### **Listing 10.14, OStimeTickHook() for $\mu$ C/OS-II**

You should also wrap the function declaration with the conditional compilation directive. The code for **OStimeTickHook()** is generated only if **OS\_CPU\_HOOKS\_EN** is set to 1 in **OS\_CFG.H**.

## 10.05 Summary

Table 10.3 provides a summary of the changes needed to bring a port for  $\mu$  C/OS to work with  $\mu$  C/OS-II. You should note that 'processor\_name.?' is the name of the  $\mu$  C/OS file containing the port.

$\mu$ C/OS	$\mu$ C/OS-II
<b>Processor_name.H</b>	<b>OS_CPU.H</b>
Data types:	Data types
Change <b>UBYTE</b> to	<b>INT8U</b>
Change <b>BYTE</b> to	<b>INT8S</b>
Change <b>UWORD</b> to	<b>INT16U</b>
Change <b>WORD</b> to	<b>INT16S</b>
Change <b>ULONG</b> to	<b>INT32U</b>
Change <b>LONG</b> to	<b>INT32S</b>
Change <b>OS_STK_TYPE</b> to	<b>OS_STK</b>
<b>OS_ENTER_CRITICAL( )</b>	No change
<b>OS_EXIT_CRITICAL( )</b>	No change
-	Add <b>OS_STK_GROWTH</b>
<b>OS_TASK_SW( )</b>	No change
<b>OS_FAR</b>	Define <b>OS_FAR</b> to nothing or, Remove all references to <b>OS_FAR</b>
<b>Processor_name.ASM</b>	<b>OS_CPU_A.ASM</b>
<b>OSStartHighRdy( )</b>	Add call to <b>OSTaskSwHook( )</b> Set <b>OSRunning</b> to 1 (8-bit)
<b>OSCtxSw( )</b>	Add call to <b>OSTaskSwHook( )</b> Copy <b>OSPrioHighRdy</b> to <b>OSPrioCur</b> (8-bit)
<b>OSIntCtxSw( )</b>	Add call to <b>OSTaskSwHook( )</b> Copy <b>OSPrioHighRdy</b> to <b>OSPrioCur</b> (8-bit)
<b>OSTickISR( )</b>	No change
<b>Processor_name.C</b>	<b>OS_CPU_C.C</b>
<b>OSTaskCreate( )</b>	Extract stack initialization code and put this code in a function called <b>OSTaskStkInit( )</b> .
-	Add an empty function called <b>OSTaskCreateHook( )</b> .
-	Add an empty function called <b>OSTaskDelHook( )</b> .
-	Add an empty function called <b>OSTaskSwHook( )</b> .
-	Add an empty function called <b>OSTaskStatHook( )</b> .
-	Add an empty function called <b>OSTimeTickHook( )</b> .

**Table 10.3, Summary of migrating a  $\mu$  C/OS port to  $\mu$  C/OS-II.**

## *Chapter 11*

# *Reference Manual*

This chapter provides a user's guide to  $\mu$  C/OS-II services. Each of the user accessible kernel services is presented in alphabetical order and the following information is provided for each of the services:

- 1) A brief description
- 2) The function prototype
- 3) The file name where the source code is found
- 4) The #define constant needed to enable the code for the service
- 5) A description of the arguments passed to the function
- 6) A description of the return value(s)
- 7) Specific notes and warning on the usage of the service
- 8) One or two examples on how to use the function

# OSInit()

void OSInit(void)

File	Called from	Code enabled by
OS_CORE.C	Startup code only	N/A

**OSInit()** is used to initialize  $\mu$  C/OS-II. **OSInit()** must be called prior to calling **OSStart()** which will actually start multitasking.

## Arguments

NONE

## Returned Value

NONE

## Notes/Warnings

**OSInit()** must be called before **OSStart()**.

## Example

```
void main (void)
{
    .
    .
    OSInit();      /* Initialize uC/OS-II */
    .
    .
    OSStart();     /* Start Multitasking */
}
```

# OSIntEnter()

void OSIntEnter(void)

File	Called from	Code enabled by
OS_CORE.C	ISR only	N/A

**OSIntEnter()** is used to notify  $\mu$  C/OS-II that an ISR is being processed. This allows  $\mu$  C/OS-II to keep track of interrupt nesting. **OSIntEnter()** is used in conjunction with **OSIntExit()**.

## Arguments

NONE

### Returned Value

NONE

### Notes/Warnings

- 1) This function must not be called by task level code.
- 2) You can actually increment the interrupt nesting counter (**OSIntNesting**) directly if your processor can perform this operation indivisibly. In other words, if your processor can perform a read-modify-write as an atomic operation then you don't need to call **OSIntEnter()** and instead, directly increment **OSIntNesting**. This would avoid the overhead associated with calling a function.

### Example #1

(Intel 80x86, RealMode, Large Model)

Here we call **OSIntEnter()** because of backward compatibility with  $\mu$ C/OS. Also, you would do this if the processor you are using does not allow you to increment **OSIntNesting** using a single instruction.

```
ISRx PROC FAR
    PUSHAD                ; Save interrupted task's context
    PUSH    ES
    PUSH    DS
;
    MOV     AX, DGROUP    ; Reload DS
    MOV     DS, AX
;
    CALL    FAR PTR _OSIntEnter ; Notify  $\mu$ C/OS-II of start of ISR
    .
    .
    POP     DS            ; Restore processor registers
    POP     ES
    POPAD
    IRET                ; Return from interrupt
ISRx ENDP
```

### Example #2

(Intel 80x86, RealMode, Large Model)

Here we increment **OSIntNesting** because the 80x86 allow you to perform this operation indivisibly.

```
ISRx PROC FAR
    PUSHAD                ; Save interrupted task's context
    PUSH    ES
    PUSH    DS
;
    MOV     AX, DGROUP    ; Reload DS
    MOV     DS, AX
;
    INC     BYTE PTR _OSIntNesting ; Notify  $\mu$ C/OS-II of start of ISR
    .
    .
    .
```



```

        POP     DS                      ; Restore processor registers
        POP     ES
        POPA
        IRET                          ; Return from interrupt
ISRx    ENDP

```

# OSIntExit()

```
void OSIntExit(void);
```

File	Called from	Code enabled by
OS_CORE.C	ISR only	N/A

**OSIntExit()** is used to notify  $\mu$  C/OS-II that an ISR has completed. This allows  $\mu$  C/OS-II to keep track of interrupt nesting. **OSIntExit()** is used in conjunction with **OSIntEnter()**. When the last nested interrupt completes,  $\mu$  C/OS-II will call the scheduler to determine if a higher priority task has been made ready to run. In this case, the interrupt will return to the higher priority task instead of the interrupted task.

### Arguments

NONE

### Returned Value

NONE

### Notes/Warnings

This function must not be called by task level code. Also, if you decided to increment **OSIntNesting** you will still need to call **OSIntExit()**.

### Example

(Intel 80x86, Real-Mode, Large Model)

```

ISRx    PROC          FAR
        PUSHA          ; Save processor registers
        PUSH     ES
        PUSH     DS
        .
        .
        CALL     FAR PTR _OSIntExit ; Notify  $\mu$ C/OS-II of end of ISR
        POP      DS      ; Restore processor registers
        POP      ES
        POPA
        IRET          ; Return to interrupted task
ISRx    ENDP

```

# OSMboxAccept()

```
void *OSMboxAccept(OS_EVENT *pevent);
```

File	Called from	Code enabled by
OS_MBOX.C	Task or ISR	OS_MBOX_EN

**OSMboxAccept()** allows you to check to see if a message is available from the desired mailbox. Unlike **OSMboxPend()**, **OSMboxAccept()** does not suspend the calling task if a message is not available. If a message is available, the message will be returned to your application and the contents of the mailbox will be cleared. This call is typically used by ISRs because an ISR is not allowed to wait for a message at a mailbox.

## Arguments

**pevent** is a pointer to the mailbox where the message is to be received from. This pointer is returned to your application when the mailbox is created (see **OSMboxCreate()**).

## Returned Value

A pointer to the message if one is available or, **NULL** if the mailbox does not contain a message.

## Notes/Warnings

Mailboxes must be created before they are used.

## Example

```
OS_EVENT *CommMbox;

void Task (void *pdata)
{
    void *msg;

    pdata = pdata;
    for (;;) {
        msg = OSMboxAccept(CommMbox); /* Check mailbox for a message */
        if (msg != (void *)0) {
            .                               /* Message received, process */
            .
        } else {
            .                               /* Message not received, do .. */
            .                               /* .. something else */
        }
        .
        .
    }
}
```

# OSMboxCreate()

```
OS_EVENT *OSMboxCreate(void *msg);
```

File	Called from	Code enabled by
OS_MBOX.C	Task or Startup code	OS_MBOX_EN

**OSMboxCreate()** is used to create and initialize a mailbox. A mailbox is used to allow tasks or ISRs to send a pointer sized variable (message) to one or more tasks.

## Arguments

**msg** is used to initialize the contents of the mailbox. The mailbox is empty when **msg** is a **NULL** pointer. The mailbox will initially contain a message when **msg** is non **NULL**.

## Returned Value

A pointer to the event control block allocated to the mailbox. If no event control block is available, **OSMboxCreate()** will return a **NULL** pointer.

## Notes/Warnings

Mailboxes must be created before they are used.

## Example

```
OS_EVENT *CommMbox;

void main(void)
{
    .
    .
    OSInit();                /* Initialize µC/OS-II */
    .
    .
    CommMbox = OSMboxCreate((void *)0); /* Create COMM mailbox */
    OSStart();                /* Start Multitasking */
}
```

# OSMboxPend()

```
void *OSMboxPend(OS_EVENT *pevent, INT16U timeout, INT8U *err);
```

File	Called from	Code enabled by
OS_MBOX.C	Task only	OS_MBOX_EN

**OSMboxPend ( )** is used when a task desires to receive a message. The message is sent to the task either by an ISR or by another task. The message received is a pointer size variable and its use is application specific. If a message is present in the mailbox when **OSMboxPend ( )** is called then, the message is retrieved, the mailbox emptied and the retrieved message is returned to the caller. If no message is present in the mailbox, **OSMboxPend ( )** will suspend the current task until either a message is received or a user specified timeout expires. If a message is sent to the mailbox and multiple tasks are waiting for such a message,  $\mu$  C/OS-II will resume the highest priority task that is waiting. A pended task that has been suspended with **OSTaskSuspend ( )** can receive a message. The task will, however, remain suspended until the task is resumed by calling **OSTaskResume ( )**.

### Arguments

**pevent** is a pointer to the mailbox where the message is to be received from. This pointer is returned to your application when the mailbox is created (see **OSMboxCreate ( )**).

**timeout** is used to allow the task to resume execution if a message is not received from the mailbox within the specified number of clock ticks. A **timeout** value of 0 indicates that the task desires to wait forever for the message. The maximum **timeout** is 65535 clock ticks. The timeout value is not synchronized with the clock tick. The timeout count starts being decremented on the next clock tick which could potentially occur immediately.

**err** is a pointer to a variable which will be used to hold an error code. **OSMboxPend ( )** sets **\*err** to either:

- 1) **OS\_NO\_ERR**, a message was received
- 2) **OS\_TIMEOUT**, a message was not received within the specified timeout period
- 3) **OS\_ERR\_PEND\_ISR**, you called this function from an ISR and  $\mu$  C/OS-II would have to suspend the ISR. In general, you should not call **OSMboxPend ( )**.  $\mu$  C/OS-II checks for this situation in case you do anyway.

### Returned Value

**OSMboxPend ( )** returns the message sent by either a task or an ISR and **\*err** is set to **OS\_NO\_ERR**. If a message is not received within the specified timeout period, the returned message will be a **NULL** pointer and **\*err** is set to **OS\_TIMEOUT**.

### Notes/Warnings

Mailboxes must be created before they are used.

### Example

```
OS_EVENT *CommMbox;

void CommTask(void *pdata)
{
    INT8U  err;
    void  *msg;

    pdata = pdata;
    for (;;) {
        .
    }
}
```

```

    .
    msg = OSMboxPend(CommMbox, 10, &err);
    if (err == OS_NO_ERR) {
        .
        . /* Code for received message */
        .
    } else {
        .
        . /* Code for message not received within timeout */
        .
    }
    .
    .
}
}

```

# OSMboxPost()

INT8U OSMboxPost(OS\_EVENT \*pevent, void \*msg);

File	Called from	Code enabled by
OS_MBOX.C	Task or ISR	OS_MBOX_EN

**OSMboxPost ( )** is used to send a message to a task through a mailbox. A message is a pointer size variable and its use is application specific. If there is already a message in the mailbox, an error code is returned indicating that the mailbox is full. **OSMboxPost ( )** will then immediately return to its caller and the message will not be placed in the mailbox. If any task is waiting for a message at the mailbox then, the highest priority task waiting will receive the message. If the task waiting for the message has a higher priority than the task sending the message then, the higher priority task will be resumed and the task sending the message will be suspended. In other words, a context switch will occur.

## Arguments

**pevent** is a pointer to the mailbox where the message is to be deposited into. This pointer is returned to your application when the mailbox is created (see **OSMboxCreate ( )**).

**msg** is the actual message sent to the task. **msg** is a pointer size variable and is application specific. You MUST never post a **NULL** pointer because this indicates that the mailbox is empty.

## Returned Value

**OSMboxPost ( )** returns one of these two error codes:

- 1) **OS\_NO\_ERR**, if the message was deposited in the mailbox
- 2) **OS\_MBOX\_FULL**, if the mailbox already contained a message

## Notes/Warnings

Mailboxes must be created before they are used.

## Example

```

OS_EVENT *CommMbox;
INT8U     CommRxBuf[100];

void CommTaskRx(void *pdata)
{
    INT8U  err;

    pdata = pdata;
    for (;;) {
        .
        .
        err = OSMboxPost(CommMbox, (void *)&CommRxBuf[0]);
        .
        .
    }
}

```

## OSMboxQuery()

```
INT8U OSMboxQuery(OS_EVENT *pevent, OS_MBOX_DATA *pdata);
```

File	Called from	Code enabled by
OS_MBOX.C	Task or ISR	OS_MBOX_EN

**OSMboxQuery()** is used to obtain information about a message mailbox. Your application must allocate an **OS\_MBOX\_DATA** data structure which will be used to receive data from the event control block of the message mailbox. **OSMboxQuery()** allows you to determine whether any task is waiting for message(s) at the mailbox, how many tasks are waiting (by counting the number of 1s in the **.OSEventTbl[]** field, and examine the contents of the contents of the message. You can use the table **OSNBitsTbl[]** to find out how many ones are set in a given byte. Note that the size of **.OSEventTbl[]** is established by the #define constant **OS\_EVENT\_TBL\_SIZE** (see **uCOS\_II.H**).

### Arguments

**pevent** is a pointer to the mailbox. This pointer is returned to your application when the mailbox is created (see **OSMboxCreate()**).

**pdata** is a pointer to a data structure of type **OS\_MBOX\_DATA** which contains the following fields:

```

void  OSMsg;           /* Copy of the message stored in the mailbox */
INT8U OSEventTbl[OS_EVENT_TBL_SIZE]; /* Copy of the mailbox wait list */
INT8U OSEventGrp;

```

### Returned Value

**OSMboxQuery()** returns one of these two error codes:

- 1) **OS\_NO\_ERR**, if the call was successful

2) **OS\_ERR\_EVENT\_TYPE**, if you didn't pass a pointer to a message mailbox

### Notes/Warnings

Message mailboxes must be created before they are used.

### Example

In this example, we check the contents of the mailbox to see how many tasks are waiting for it.

```
OS_EVENT *CommMbox;

void Task (void *pdata)
{
    OS_MBOXDATA mbox_data;
    INT8U      err;
    INT8U      nwait;          /* Number of tasks waiting on mailbox */
    INT8U      i;

    pdata = pdata;
    for (;;) {
        .
        .
        err = OSMboxQuery(CommMbox, &mbox_data);
        if (err == OS_NO_ERR) {
            nwait = 0;          /* Count # tasks waiting on mailbox */
            if (mbox_data.OSEventGrp != 0x00) {
                for (i = 0; i < OS_EVENT_TBL_SIZE; i++) {
                    nwait += OSNBitsTbl[mbox_data.OSEventTbl[i]];
                }
            }
        }
        .
        .
    }
}
```

# OSMemCreate()

```
OS_MEM *OSMemCreate(void *addr, INT32U nblks, INT32U blksize, INT8U *err);
```

File	Called from	Code enabled by
OS_MEM.C	Task or startup code	OS_MEM_EN

**OSMemCreate()** is used to create and initialize a memory partition. A memory partition contains a user-specified number of fixed-sized memory blocks. Your application can obtain one of these memory blocks and when done, release the block back to the partition.

### Arguments

**addr** is the address of the start of a memory area that will be used to create fixed-sized memory blocks. Memory partitions can either be created using static arrays or malloc'ed during startup.

**nblks** contains the number of memory blocks available from the specified partition. You **MUST** specify at least 2 memory blocks per partition.

**blksize** specifies the size (in bytes) of each memory block within a partition. A memory block **MUST** be large enough to hold at least a pointer.

**err** is a pointer to a variable which will be used to hold an error code. **OSMemCreate()** sets **\*err** to either:

- 1) **OS\_NO\_ERR**, if the memory partition was created successfully.
- 2) **OS\_MEM\_INVALID\_PART**, if a free memory partition is not available.
- 3) **OS\_MEM\_INVALID\_BLKS**, if you didn't specify at least 2 memory blocks per partition.
- 4) **OS\_MEM\_INVALID\_SIZE**, if you didn't specify a block size that can at least contain a pointer variable.

### Returned Value

**OSMemCreate()** returns a pointer to the created memory partition control block if one is available. If no memory partition control block is available, **OSMemCreate()** will return a **NULL** pointer.

### Notes/Warnings

Memory partitions must be created before they are used.

### Example

```
OS_MEM *CommMem;
INT8U   CommBuf[16][128];

void main(void)
{
    INT8U err;

    OSInit();                      /* Initialize µC/OS-II          */
    .
    .
    CommMem = OSMemCreate(&CommBuf[0][0], 16, 128, &err);
    .
    .
    OSStart();                     /* Start Multitasking          */
}
```

# OSMemGet()

```
void *OSMemGet(OS_MEM *pmem, INT8U *err);
```



File	Called from	Code enabled by
OS_MEM.C	Task or ISR	OS_MEM_EN

**OSMemGet ( )** is used to obtain a memory block from a memory partition. It is assumed that your application will know the size of each memory block obtained. Also, your application **MUST** return the memory block (using **OSMemPut ( )**) when it no longer needs it. You can call **OSMemGet ( )** more than once until all memory blocks are allocated.

### Arguments

**pmem** is a pointer to the memory partition control block that was returned to your application from the **OSMemCreate ( )** call.

**err** is a pointer to a variable which will be used to hold an error code. **OSMemGet ( )** sets **\*err** to either:

- 1) **OS\_NO\_ERR**, if a memory block was available and returned to your application.
- 2) **OS\_MEM\_NO\_FREE\_BLKs**, if the memory partition doesn't contain any more memory blocks to allocate.

### Returned Value

**OSMemGet ( )** returns a pointer to the allocated memory block if one is available. If no memory block is available from the memory partition, **OSMemGet ( )** will return a **NULL** pointer.

### Notes/Warnings

Memory partitions must be created before they are used.

### Example

```
OS_MEM *CommMem;

void Task (void *pdata)
{
    INT8U *msg;

    pdata = pdata;
    for (;;) {
        msg = OSMemGet(CommMem, &err);
        if (msg != (INT8U *)0) {
            .                /* Memory block allocated, use it. */
            .
        }
        .
        .
    }
}
```

# OSMemPut()

```
INT8U OSMemPut(OS_MEM *pmem, void *pblk);
```

File	Called from	Code enabled by
OS_MEM.C	Task or ISR	OS_MEM_EN

**OSMemPut ( )** is used to return a memory block to a memory partition. It is assumed that you will return the memory block to the appropriate memory partition.

## Arguments

**pmem** is a pointer to the memory partition control block that was returned to your application from the **OSMemCreate ( )** call.

**pblk** is a pointer to the memory block to return back to the memory partition.

## Returned Value

**OSMemPut ( )** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if a memory block was available and returned to your application.
- 2) **OS\_MEM\_FULL**, if the memory partition cannot accept any more memory blocks. This is surely an indication that something went wrong as you returned more memory blocks that you obtained using **OSMemGet ( )**.

## Notes/Warnings

Memory partitions must be created before they are used.

## Example

```
OS_MEM *CommMem;
INT8U *CommMsg;

void Task (void *pdata)
{
    INT8U err;

    pdata = pdata;
    for (;;) {
        err = OSMemPut(CommMem, (void *)CommMsg);
        if (err == OS_NO_ERR) {
            .                /* Memory block released          */
            .
        }
        .
        .
    }
}
```

```
}
```

# OSMemQuery()

```
INT8U OSMemQuery(OS_MEM *pmem, OS_MEM_DATA *pdata);
```

File	Called from	Code enabled by
OS_MEM.C	Task or ISR	OS_MEM_EN

**OSMemQuery()** is used to obtain information about a memory partition. Basically, this function returns the same information found in the **OS\_MEM** data structure but, in a new data structure called **OS\_MEM\_DATA**. **OS\_MEM\_DATA** also contains an additional field that indicates the number of memory blocks in use.

## Arguments

**pmem** is a pointer to the memory partition control block that was returned to your application from the **OSMemCreate()** call.

**pdata** is a pointer to a data structure of type **OS\_MEM\_DATA** which contains the following fields:

```
void    *OSAddr;      /* Points to beginning address of the memory partition */
void    *OSFreeList;  /* Points to beginning of the free list of memory blocks */
INT32U  OSBlkSize;    /* Size (in bytes) of each memory block */
INT32U  OSNBlks;      /* Total number of blocks in the partition */
INT32U  OSNFree;      /* Number of memory blocks free */
INT32U  OSNUsed;      /* Number of memory blocks used */
```

## Returned Value

**OSMemQuery()** always returns **OS\_NO\_ERR**.

## Notes/Warnings

Memory partitions must be created before they are used.

## Example

```
OS_MEM      *CommMem;
OS_MEM_DATA  mem_data;

void Task (void *pdata)
{
    INT8U err;

    pdata = mem_data;
    for (;;) {
        .
        .
    }
```

```

        err = OSMemOuerv(CommMem, &mem data);
        .
        .
    }
}

```

# OSQAccept()

```
void *OSQAccept(OS_EVENT *pevent);
```

File	Called from	Code enabled by
OS_Q.C	Task or ISR	OS_Q_EN

**OSQAccept()** allows you to check to see if a message is available from the desired message queue. Unlike **OSQPend()**, **OSQAccept()** does not suspend the calling task if a message is not available. If a message is available, the message will be returned to your application and the message will be extracted from the queue. This call is typically used by ISRs because an ISR is not allowed to wait for messages at a queue.

## Arguments

**pevent** is a pointer to the message queue where the message is to be received from. This pointer is returned to your application when the message queue is created (see **OSQCreate()**).

## Returned Value

A pointer to the message if one is available or, **NULL** if the message queue does not contain a message.

## Notes/Warnings

Message queues must be created before they are used.

## Example

```

OS_EVENT *CommQ;

void Task (void *pdata)
{
    void *msg;

    pdata = pdata;
    for (;;) {
        msg = OSQAccept(CommQ); /* Check queue for a message */
        if (msg != (void *)0) {
            . /* Message received, process */
            .
        } else {
            . /* Message not received, do .. */
        }
    }
}

```



# OSQFlush()

INT8U \*OSQFlush(OS\_EVENT \*pevent);

File	Called from	Code enabled by
OS_Q.C	Task or ISR	OS_Q_EN

**OSQFlush()** is used to empty the contents of the message queue and basically eliminate all the messages sent to the queue. This function takes the same amount of time to execute whether tasks are waiting on the queue (and thus no messages are present) or the queue contains one or more messages.

## Arguments

**pevent** is a pointer to the message queue. This pointer is returned to your application when the message queue is created (see **OSQCreate()**).

## Returned Value

One of the following codes:

- 1) **OS\_NO\_ERR**, the message queue was flushed.
- 2) **OS\_ERR\_EVENT\_TYPE**, if you attempted to flush an object other than a message queue.

## Notes/Warnings

Queues must be created before they are used.

## Example

```
OS_EVENT *CommQ;

void main(void)
{
    INT8U err;

    OSInit();                      /* Initialize µC/OS-II */
    .
    .
    err = OSQFlush(CommQ);
    .
    .
    OSStart();                     /* Start Multitasking */
}
```

# OSQPend()

void \*OSQPend(OS\_EVENT \*pevent, INT16U timeout, INT8U \*err);

File	Called from	Code enabled by
OS_Q.C	Task only	OS_Q_EN

**OSQPend ( )** is used when a task desires to receive messages from a queue. The messages are sent to the task either by an ISR or by another task. The messages received are pointer size variables and their use is application specific. If a at least one message is present at the queue when **OSQPend ( )** is called, the message is retrieved and returned to the caller. If no message is present at the queue, **OSQPend ( )** will suspend the current task until either a message is received or a user specified timeout expires. If a message is sent to the queue and multiple tasks are waiting for such a message then,  $\mu$  C/OS-II will resume the highest priority task that is waiting. A pended task that has been suspended with **OSTaskSuspend ( )** can receive a message. The task will, however, remain suspended until the task is resumed by calling **OSTaskResume ( )**.

#### Arguments

**pevent** is a pointer to the queue where the messages are to be received from. This pointer is returned to your application when the queue is created (see **OSQCreate ( )**).

**timeout** is used to allow the task to resume execution if a message is not received from the mailbox within the specified number of clock ticks. A **timeout** value of 0 indicates that the task desires to wait forever for the message. The maximum **timeout** is 65535 clock ticks. The timeout value is not synchronized with the clock tick. The timeout count starts being decremented on the next clock tick which could potentially occur immediately.

**err** is a pointer to a variable which will be used to hold an error code. **OSQPend ( )** sets **\*err** to either:

- 1) **OS\_NO\_ERR**, a message was received
  - 2) **OS\_TIMEOUT**, a message was not received within the specified timeout
  - 3) **OS\_ERR\_PEND\_ISR**, you called this function from an ISR and  $\mu$  C/OS-II would have to suspend the ISR.
- In general, you should not call **OSQPend ( )**.  $\mu$  C/OS-II checks for this situation in case you do anyway.

#### Returned Value

**OSQPend ( )** returns a message sent by either a task or an ISR and **\*err** is set to **OS\_NO\_ERR**. If a timeout occurred, **OSQPend ( )** returns a **NULL** pointer and sets **\*err** to **OS\_TIMEOUT**.

#### Notes/Warnings

Queues must be created before they are used.

#### Example

```
OS_EVENT *CommQ;

void CommTask(void *data)
{
    INT8U  err;
    void  *msg;

    pdata = pdata;
```

```

for (;;) {
    .
    .
    msg = OSQPend(CommQ, 100, &err);
    if (err == OS_NO_ERR) {
        .
        .          /* Message received within 100 ticks!          */
        .
    } else {
        .
        .          /* Message not received, must have timed out    */
        .
    }
    .
    .
}
}

```

# OSQPost()

INT8U OSQPost(OS\_EVENT \*pevent, void \*msg);

File	Called from	Code enabled by
OS_Q.C	Task or ISR	OS_Q_EN

**OSQPost ( )** is used to send a message to a task through a queue. A message is a pointer size variable and its use is application specific. If the message queue is full an error code is returned to the caller. **OSQPost ( )** will then immediately return to its caller and the message will not be placed in the queue. If any task is waiting for a message at the queue then, the highest priority task will receive the message. If the task waiting for the message has a higher priority than the task sending the message then, the higher priority task will be resumed and the task sending the message will be suspended. In other words, a context switch will occur. Message queues are first-in-first-out (FIFO) which means that the first message sent will be the first message received.

## Arguments

**pevent** is a pointer to the queue where the message is to be deposited into. This pointer is returned to your application when the queue is created (see **OSQCreate ( )**).

**msg** is the actual message sent to the task. **msg** is a pointer size variable and is application specific. You MUST never post a NULL pointer.

## Returned Value

**OSQPost ( )** returns one of these two error codes

- 1) **OS\_NO\_ERR**, if the message was deposited in the queue
- 2) **OS\_Q\_FULL**, if the queue is already full

## Notes/Warnings



Queues must be created before they are used.

#### Example

```
OS_EVENT *CommQ;
INT8U     CommRxBuf[100];

void CommTaskRx(void *pdata)
{
    INT8U  err;

    pdata = pdata;
    for (;;) {
        .
        .
        err = OSQPost(CommQ, (void *)&CommRxBuf[0]);
        if (err == OS_NO_ERR) {
            .
            .
            /* Message was deposited into queue */
        } else {
            .
            .
            /* Queue is full */
        }
        .
        .
    }
}
```

## OSQPostFront()

```
INT8U OSQPostFront(OS_EVENT *pevent, void *msg);
```

File	Called from	Code enabled by
OS_Q.C	Task or ISR	OS_Q_EN

**OSQPostFront()** is used to send a message to a task through a queue. **OSQPostFront()** behaves very much like **OSQPost()** except that the message is inserted at the front of the queue. This means that **OSQPostFront()** makes the message queue behave like a last-in-first-out (LIFO) queue instead of a first-in-first-out (FIFO) queue. A message is a pointer size variable and its use is application specific. If the message queue is full an error code is returned to the caller. **OSQPostFront()** will then immediately return to its caller and the message will not be placed in the queue. If any task is waiting for a message at the queue then, the highest priority task will receive the message. If the task waiting for the message has a higher priority than the task sending the message then, the higher priority task will be resumed and the task sending the message will be suspended. In other words, a context switch will occur.

#### Arguments

**pevent** is a pointer to the queue where the message is to be deposited into. This pointer is returned to your application when the queue is created (see **OSQCreate()**).

**msg** is the actual message sent to the task. **msg** is a pointer size variable and is application specific. You MUST never post a NULL pointer.

### Returned Value

**OSQPostFront()** returns one of these two error codes

- 1) **OS\_NO\_ERR**, if the message was deposited in the queue
- 2) **OS\_Q\_FULL**, if the queue is already full

### Notes/Warnings

Queues must be created before they are used.

### Example

```
OS_EVENT *CommQ;
INT8U     CommRxBuf[100];

void CommTaskRx(void *pdata)
{
    INT8U  err;

    pdata = pdata;
    for (;;) {
        .
        .
        err = OSQPostFront(CommQ, (void *)&CommRxBuf[0]);
        if (err == OS_NO_ERR) {
            .                /* Message was deposited into queue */
            .
        } else {
            .                /* Queue is full */
            .
        }
        .
        .
    }
}
```

# OSQQuery()

**INT8U OSQQuery(OS\_EVENT \*pevent, OS\_Q\_DATA \*pdata);**

File	Called from	Code enabled by
OS_Q.C	Task or ISR	OS_MBOX_EN

**OSQQuery ( )** is used to obtain information about a message queue. Your application must allocate an **OS\_Q\_DATA** data structure which will be used to receive data from the event control block of the message queue. **OSQQuery ( )** allows you to determine whether any task is waiting for message(s) at the queue, how many tasks are waiting (by counting the number of 1s in the **.OSEventTbl[ ]** field, how many messages are in the queue, what the message queue size is, and examine the contents of the next message that would be returned if there is at least one message in the queue. You can use the table **OSNBitsTbl[ ]** to find out how many ones are set in a given byte. Note that the size of **.OSEventTbl[ ]** is established by the **#define** constant **OS\_EVENT\_TBL\_SIZE** (see **uCOS\_II.H**).

### Arguments

**pevent** is a pointer to the message queue. This pointer is returned to your application when the queue is created (see **OSQCreate ( )**).

**pdata** is a pointer to a data structure of type **OS\_Q\_DATA** which contains the following fields.

```
void *OSMsg;           /* Next message if one available */
INT16U OSNmsgs;        /* Number of messages in the queue */
INT16U OSQSize;        /* Size of the message queue */
INT8U OSEventTbl[OS_EVENT_TBL_SIZE]; /* Message queue wait list */
INT8U OSEventGrp;
```

### Returned Value

**OSQQuery ( )** returns one of these two error codes:

- 1) **OS\_NO\_ERR**, if the call was successful
- 2) **OS\_ERR\_EVENT\_TYPE**, if you didn't pass a pointer to a message queue

### Notes/Warnings

Message queues must be created before they are used.

### Example

In this example, we check the contents of the message queue to see how many tasks are waiting for it.

```
OS_EVENT *CommQ;

void Task (void *pdata)
{
    OS_Q_DATA qdata;
    INT8U err;
    INT8U nwait;           /* Number of tasks waiting on queue */
    INT8U i;

    pdata = pdata;
    for (;;) {
        .
        .
        .
    }
}
```

```

err = OSOQuery(CommO, &qdata);
if (err == OS_NO_ERR) {
    nwait = 0;          /* Count # tasks waiting on queue */
    if (qdata.OSEventGrp != 0x00) {
        for (i = 0; i < OS_EVENT_TBL_SIZE; i++) {
            nwait += OSNBitsTbl[qdata.OSEventTbl[i]];
        }
    }
}
.
.
}

```

# OSSchedLock()

void OSSchedLock(void);

File	Called from	Code enabled by
OS_CORE.C	Task or ISR	N/A

**OSSchedLock()** is used to prevent task rescheduling until its counterpart, **OSSchedUnlock()**, is called. The task which calls **OSSchedLock()** keeps control of the CPU even though other higher priority tasks are ready to run. However, interrupts will still be recognized and serviced (assuming interrupts are enabled). **OSSchedLock()** and **OSSchedUnlock()** must be used in pair.  $\mu$ C/OS-II allows **OSSchedLock()** to be nested up to 254 levels deep. Scheduling is enabled when an equal number of **OSSchedUnlock()** calls have been made.

## Arguments

NONE

## Returned Value

NONE

## Notes/Warnings

After calling **OSSchedLock()**, your application must not make any system call which will suspend execution of the current task i.e., your application cannot call **OSTimeDly()**, **OSTimeDlyHMSM()**, **OSSemPend()**, **OSMboxPend()** or **OSQPend()**. Since the scheduler is locked out, no other task will be allowed to run and your system will lock up.

## Example

```

void TaskX(void *pdata)
{
    pdata = pdata;
    for (;;) {
        .
        OSSchedLock();    /* Prevent other tasks to run      */
    }
}

```

```

        .
        .                /* Code protected from context switch */
        .
    OSSchedUnlock(); /* Enable other tasks to run          */
        .
    }
}

```

# OSSchedUnlock()

void OSSchedUnlock(void);

File	Called from	Code enabled by
OS_CORE.C	Task or ISR	N/A

**OSSchedUnlock()** is used to re-enable task scheduling. **OSSchedUnlock()** is used with **OSSchedLock()** in pair. Scheduling is enabled when an equal number of **OSSchedUnlock()** as **OSSchedLock()** have been made.

## Arguments

NONE

## Returned Value

NONE

## Notes/Warnings

After calling **OSSchedLock()**, you application must not make any system call which will suspend execution of the current task i.e., your application cannot call **OSTimeDly()**, **OSTimeDlyHMSM()**, **OSSemPend()**, **OSMboxPend()** or **OSQPend()**. Since the scheduler is locked out, no other task will be allowed to run and your system will lock up.

## Example

```

void TaskX(void *pdata)
{
    pdata = pdata;
    for (;;) {
        .
        OSSchedLock();    /* Prevent other tasks to run          */
        .
        .                /* Code protected from context switch */
        .
        OSSchedUnlock(); /* Enable other tasks to run          */
        .
    }
}

```

# OSSemAccept()

INT16U OSMemAccept(OS\_EVENT \*pevent);

File	Called from	Code enabled by
OS_SEM.C	Task or ISR	OS_SEM_EN

**OSMemAccept()** allows you to check to see if a resource is available or an event occurred. Unlike **OSMemPend()**, **OSMemAccept()** does not suspend the calling task if the resource is not available. You would use **OSMemAccept()** from an ISR to obtain the semaphore.

## Arguments

**pevent** is a pointer to the semaphore that guards the resource. This pointer is returned to your application when the semaphore is created (see **OSMemCreate()**).

## Returned Value

When the semaphore value is greater than 0 when **OSMemAccept()** is called then, the semaphore value is decremented and the value of the semaphore before the decrement is returned to your application. If, however, the semaphore value is 0 then, the resource is not available and 0 is returned to your application.

## Notes/Warnings

Semaphores must be created before they are used.

## Example

```
OS_EVENT *DispSem;

void Task (void *pdata)
{
    INT16U value;

    pdata = pdata;
    for (;;) {
        value = OSMemAccept(DispSem); /* Check resource availability */
        if (value > 0) {
            .                               /* Resource available, process */
            .
        }
        .
        .
    }
}
```

# OSSemCreate()

`OS_EVENT *OSSemCreate(WORD value);`

File	Called from	Code enabled by
OS_SEM.C	Task or startup code	OS_SEM_EN

**OSSemCreate()** is used to create and initialize a semaphore. A semaphore is used to:

- 1) Allow a task to synchronize with either an ISR or a task
- 2) Gain exclusive access to a resource
- 3) Signal the occurrence of an event

## Arguments

**value** is the initial value of the semaphore. The initial **value** of the semaphore is allowed to be between 0 and 65535.

## Returned Value

A pointer to the event control block allocated to the semaphore. If no event control block is available, **OSSemCreate()** will return a **NULL** pointer.

## Notes/Warnings

Semaphores must be created before they are used.

## Example

```
OS_EVENT *DispSem;

void main(void)
{
    .
    .
    OSInit();                /* Initialize µC/OS-II          */
    .
    .
    DispSem = OSMemCreate(1); /* Create Display Semaphore */
    .
    .
    OSStart();               /* Start Multitasking      */
}
```

# OSSemPend()

`void OSMemPend(OS_EVENT *pevent, INT16U timeout, INT8U *err);`

File	Called from	Code enabled by
------	-------------	-----------------

OS_SEM.C	Task only	OS_SEM_EN
----------	-----------	-----------

**OSSemPend( )** is used when a task desires to get exclusive access to a resource, synchronize its activities with an ISR, a task or until an event occurs. If a task calls **OSSemPend( )** and the value of the semaphore is greater than 0, then **OSSemPend( )** will decrement the semaphore and return to its caller. However, if the value of the semaphore is equal to zero, **OSSemPend( )** places the calling task in the waiting list for the semaphore. The task will thus wait until a task or an ISR signals the semaphore or, the specified timeout expires. If the semaphore is signaled before the timeout expires,  $\mu$  C/OS-II will resume the highest priority task that is waiting for the semaphore. A pending task that has been suspended with **OSTaskSuspend( )** can obtain the semaphore. The task will, however, remain suspended until the task is resumed by calling **OSTaskResume( )**.

### Arguments

**pevent** is a pointer to the semaphore. This pointer is returned to your application when the semaphore is created (see **OSSemCreate( )**).

**timeout** is used to allow the task to resume execution if a message is not received from the mailbox within the specified number of clock ticks. A **timeout** value of 0 indicates that the task desires to wait forever for the message. The maximum **timeout** is 65535 clock ticks. The timeout value is not synchronized with the clock tick. The timeout count starts being decremented on the next clock tick which could potentially occur immediately.

**err** is a pointer to a variable which will be used to hold an error code. **OSSemPend( )** sets **\*err** to either:

- 1) **OS\_NO\_ERR**, the semaphore is available
  - 2) **OS\_TIMEOUT**, the semaphore was not signaled within the specified timeout
  - 3) **OS\_ERR\_PEND\_ISR**, you called this function from an ISR and  $\mu$  C/OS-II would have to suspend the ISR.
- In general, you should not call **OSMboxPend( )**.  $\mu$  C/OS-II checks for this situation in case you do anyway.

### Returned Value

NONE

### Notes/Warnings

Semaphores must be created before they are used.

### Example

```
OS_EVENT *DispSem;

void DispTask(void *pdata)
{
    INT8U  err;

    pdata = pdata;
    for (;;) {
        .
    }
}
```



```

    OSSEmPend(DispSem, 0, &err);
    /* The only way this task continues is if ... */
    /* ... the semaphore is signaled!           */
}
}

```

# OSSemPost()

```
INT8U OSSemPost(OS_EVENT *pevent);
```

File	Called from	Code enabled by
OS_SEM.C	Task or ISR	OS_SEM_EN

A semaphore is signaled by calling `OSSemPost()`. If the semaphore value is greater than or equal to zero, the semaphore is incremented and `OSSemPost()` returns to its caller. If tasks are waiting for the semaphore to be signaled then, `OSSemPost()` removes the highest priority task pending (waiting) for the semaphore from the waiting list and makes this task ready to run. The scheduler is then called to determine if the awakened task is now the highest priority task ready to run.

## Arguments

**pevent** is a pointer to the semaphore. This pointer is returned to your application when the semaphore is created (see `OSSemCreate()`).

## Returned Value

**OSSemPost()** returns one of these two error codes

- 1) **OS\_NO\_ERR**, if the semaphore was successfully signaled
- 2) **OS\_SEM\_OVF**, if the semaphore count overflowed

## Notes/Warnings

Semaphores must be created before they are used.

### Example

```
OS_EVENT *DispSem;

void TaskX(void *pdata)
{
    INT8U  err;

    pdata = pdata;
    for (;;) {
        .
        .
        err = OSSemPost(DispSem);
    }
}
```

```

        if (err == OS_NO_ERR) {
            .
            .
            .
        } else {
            .
            .
            .
        }
        .
        .
    }
}

```

# OSSemQuery()

```
INT8U OSSemQuery(OS_EVENT *pevent, OS_SEM_DATA *pdata);
```

File	Called from	Code enabled by
OS_SEM.C	Task or ISR	OS_SEM_EN

**OSSemQuery()** is used to obtain information about a semaphore. Your application must allocate an **OS\_SEM\_DATA** data structure which will be used to receive data from the event control block of the semaphore. **OSSemQuery()** allows you to determine whether any task is waiting on the semaphore, how many tasks are waiting (by counting the number of 1s in the **.OSEventTbl[]** field, and obtain the semaphore count. You can use the table **OSNBitsTbl[]** to find out how many ones are set in a given byte. Note that the size of **.OSEventTbl[]** is established by the **#define** constant **OS\_EVENT\_TBL\_SIZE** (see **uCOS\_II.H**).

## Arguments

**pevent** is a pointer to the semaphore. This pointer is returned to your application when the semaphore is created (see **OSSemCreate()**).

**pdata** is a pointer to a data structure of type **OS\_SEM\_DATA** which contains the following fields.

```

INT16U OSCnt;                /* Current semaphore count */
INT8U  OSEventTbl[OS_EVENT_TBL_SIZE]; /* Semaphore wait list */
INT8U  OSEventGrp;

```

## Returned Value

**OSSemQuery()** returns one of these two error codes:

- 1) **OS\_NO\_ERR**, if the call was successful
- 2) **OS\_ERR\_EVENT\_TYPE**, if you didn't pass a pointer to a semaphore

## Notes/Warnings

Semaphores must be created before they are used.

## Example

In this example, we check the contents of the semaphore to determine the highest priority task that is waiting for it.

```
OS_EVENT *DispSem;

void Task (void *pdata)
{
    OS_SEM_DATA sem_data;
    INT8U      err;
    INT8U      highest; /* Highest priority task waiting on semaphore */
    INT8U      x;
    INT8U      y;

    pdata = pdata;
    for (;;) {
        .
        .
        err = OSSemQuery(DispSem, &sem_data);
        if (err == OS_NO_ERR) {
            if (sem_data.OSEventGrp != 0x00) {
                y      = OSUnMapTbl[sem_data.OSEventGrp];
                x      = OSUnMapTbl[sem_data.OSEventTbl[y]];
                highest = (y << 3) + x;
                .
                .
            }
        }
        .
        .
    }
}
```

# OSStart()

void OSStart(void);

File	Called from	Code enabled by
OS_CORE.C	Startup code only	N/A

**OSStart()** is used to start multitasking under  $\mu$ C/OS-II.

## Arguments

NONE

## Returned Value

NONE

## Notes/Warnings

**OSInit()** must be called prior to calling **OSStart()**. **OSStart()** should only called once by your application code. If you do call **OSStart()** more than once, **OSStart()** will not do anything on the second and subsequent calls.

#### Example

```
void main(void)
{
    .                /* User Code          */
    .
    OSInit();         /* Initialize uC/OS-II */
    .                /* User Code          */
    .
    OSStart();        /* Start Multitasking */
}
```

## OSStatInit()

**void OSStatInit(void);**

File	Called from	Code enabled by
OS_CORE.C	Startup code only	OS_TASK_STAT_EN && OS_TASK_CREATE_EXT_EN

**OSStatInit()** is used to have uC/OS-II determine the maximum value that a 32-bit counter can reach when no other task is executing. This function must be called when there is only one task created in your application and, when multitasking has started. In other words, this function must be called from the first, and only created task.

#### Arguments

NONE

#### Returned Value

NONE

#### Notes/Warnings

NONE

#### Example

```
void FirstAndOnlyTask (void *pdata)
{
    .
    .
    OSStatInit();      /* Compute CPU capacity with no task running */
    .
}
```

```

OSTaskCreate(...);    /* Create the other tasks          */
OSTaskCreate(...);

.
for (;;) {
    .
    .
}
}

```

# OSTaskChangePrio()

INT8U OSTaskChangePrio(INT8U oldprio, INT8U newprio);

File	Called from	Code enabled by
OS_TASK.C	Task only	OS_TASK_CHANGE_PRIO_EN

**OSTaskChangePrio()** allows you to change the priority of a task.

## Arguments

**oldprio** is the priority number of the task to change.

**newprio** is the new task's priority.

## Returned Value

**OSTaskChangePrio()** returns one of these error codes:

- 1) **OS\_NO\_ERR**, the task's priority was changed
- 2) **OS\_PRIO\_INVALID**, if either the old priority or the new priority exceeds the maximum number of tasks allowed
- 3) **OS\_PRIO\_EXIST**, if **newp** already existed
- 4) **OS\_PRIO\_ERR**, there is no task with the specified 'old' priority (i.e. the task specified by **oldprio** does not exist)

## Notes/Warnings

The desired priority must not have already been assigned, otherwise, an error code is returned. Also, **OSTaskChangePrio()** verifies that the task to change exist.

## Example

```

void TaskX(void *data)
{
    INT8U err;

    for (;;) {
        .
        .
    }
}

```

```

        err = OSTaskChangePrio(10, 15);
        .
        .
    }
}

```

# OSTaskCreate()

```
INT8U OSTaskCreate(void (*task)(void *pd), void *pdata, OS_STK *ptos, INT8U prio);
```

File	Called from	Code enabled by
OS_TASK.C	Task or startup code	N/A

**OSTaskCreate()** allows an application to create a task so it can be managed by  $\mu$ C/OS-II. Tasks can either be created prior to the start of multitasking or by a running task. A task cannot be created by an ISR. A task **MUST** be written as an infinite loop as shown in the example below and, **MUST NOT** return.

**OSTaskCreate()** is used for backward compatibility with  $\mu$ C/OS and when the added features of **OSTaskCreateExt()** are not needed.

Depending on how the stack frame was built, your task will either have interrupts enable or disabled. You will need to check with the processor specific code for details.

## Arguments

**task** is a pointer to the task's code.

**pdata** is a pointer to an optional data area which can be used to pass parameters to the task when it is created. Where the task is concerned, it thinks it was invoked and passed the argument **pdata** as follows:

```

void Task (void *pdata)
{
    .
    .
    .
    /* Do something with 'pdata' */
    for (;;) {
        .
        .
        .
        /* Must call one of the following services: */
        /* OSMboxPend() */
        /* OSQPend() */
        /* OSSemPend() */
        /* OSTimeDly() */
        /* OSTimeDlyHMSM() */
        /* OSTaskSuspend() (Suspend self) */
        /* OSTaskDel() (Delete self) */
        .
        .
    }
}

```

**ptos** is a pointer to the task's top of stack. The stack is used to store local variables, function parameters, return addresses and CPU registers during an interrupt. The size of the stack is determined by the task's requirements and, the

anticipated interrupt nesting. Determining the size of the stack involves knowing how many bytes are required for storage of local variables for the task itself, all nested functions, as well as requirements for interrupts (accounting for nesting). If the configuration constant **OS\_STK\_GROWTH** is set to 1, the stack is assumed to grow downward (i.e. from high memory to low memory). **ptos** will thus need to point to the highest *valid* memory location on the stack. If **OS\_STK\_GROWTH** is set to 0, the stack is assumed to grow in the opposite direction (i.e. from low memory to high memory).

**prio** is the task priority. A unique priority number must be assigned to each task and the lower the number, the higher the priority.

### Returned Value

**OSTaskCreate ( )** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if the function was successful
- 2) **OS\_PRIO\_EXIST**, if the requested priority already exist

### Notes/Warnings

The stack **MUST** be declared with the **OS\_STK** type.

A task **MUST** always invoke one of the services provided by  $\mu$  C/OS-II to either wait for time to expire, suspend the task or, wait an event to occur (wait on a mailbox, queue or semaphore). This will allow other tasks to gain control of the CPU.

You should not use task priorities 0, 1, 2, 3 and **OS\_LOWEST\_PRIO-3**, **OS\_LOWEST\_PRIO-2**, **OS\_LOWEST\_PRIO-1** and **OS\_LOWEST\_PRIO** because they are reserved for  $\mu$  C/OS-II's use. This thus leaves you with up to 56 application tasks.

### Example #1

This examples shows that the argument that **Task1 ( )** will receive is not used and thus, the pointer **pdata** is set to **NULL**. Note that I assumed that the stack grows from high memory to low memory because I passed the address of the highest valid memory location of the stack **Task1Stk[ 1]**. If the stack grows in the opposite direction for the processor you are using, you will need to pass **Task1Stk[ 0]** as the task's top-of-stack.

```
OS_STK *Task1Stk[1024];
INT8U   Task1Data;

void main(void)
{
    INT8U err;

    .
    OSInit();                /* Initialize  $\mu$ C/OS-II          */
    .
    OSTaskCreate(Task1,
                  (void *)&Task1Data,
                  &Task1Stk[1023],
                  25);
    .
    OSStart();               /* Start Multitasking      */
}
```

```

}

void Task1(void *pdata)
{
    pdata = pdata;
    for (;;) {
        .                               /* Task code                               */
        .
    }
}

```

### Example #2

It is possible to create a 'generic' task that can be instantiated more than once. For example, a task can handle a serial port and the task would be passed the address of a data structure that characterizes the specific port (i.e. port address, baud rate, etc.).

```

OS_STK    *Comm1Stk[1024];
COMM_DATA  Comm1Data;          /* Data structure containing COMM port    */
                                   /* Specific data for channel 1            */

OS_STK    *Comm2Stk[1024];
COMM_DATA  Comm2Data;          /* Data structure containing COMM port    */
                                   /* Specific data for channel 2            */

void main(void)
{
    INT8U err;

    .
    OSInit();                    /* Initialize µC/OS-II                    */
    .
    OSTaskCreate(CommTask,
                 (void *)&Comm1Data,
                 &Comm1Stk[1023],
                 25);
    OSTaskCreate(CommTask,
                 (void *)&Comm2Data,
                 &Comm2Stk[1023],
                 26);
    .
    OSStart();                   /* Start Multitasking                      */
}

void CommTask(void *pdata)      /* Generic communication task             */
{
    for (;;) {
        .                               /* Task code                               */
        .
    }
}

```



```
}
```

# OSTaskCreateExt()

```
INT8U OSTaskCreateExt(void (*task)(void *pd), void *pdata, OS_STK *ptos, INT8U prio,
                      INT16U, id, OS_STK *pbos, INT32U stk_size, void *pext, INT16U opt);
```

File	Called from	Code enabled by
OS_TASK.C	Task or startup code	N/A

**OSTaskCreateExt()** allows an application to create a task so it can be managed by  $\mu$ C/OS-II. This function serves the same purpose as **OSTaskCreate()** except that it allows you to specify additional information about your task to  $\mu$ C/OS-II. Tasks can either be created prior to the start of multitasking or by a running task. A task cannot be created by an ISR. A task **MUST** be written as an infinite loop as shown in the example code below and, **MUST NOT** return. Depending on how the stack frame was built, your task will either have interrupts enable or disabled. You will need to check with the processor specific code for details. You should note that the first four arguments are exactly the same as the ones for **OSTaskCreate()**. This was done to simplify the migration to this new, and more powerful function.

## Arguments

**task** is a pointer to the task's code.

**pdata** is a pointer to an optional data area which can be used to pass parameters to the task when it is created. Where the task is concerned, it thinks it was invoked and passed the argument **pdata** as follows:

```
void Task (void *pdata)
{
    .
    .
    .
    /* Do something with 'pdata' */
    for (;;) {
        /* Task body, always an infinite loop. */
        .
        .
        /* Must call one of the following services: */
        /* OSMboxPend() */
        /* OSQPend() */
        /* OSSemPend() */
        /* OSTimeDly() */
        /* OSTimeDlyHMSM() */
        /* OSTaskSuspend() (Suspend self) */
        /* OSTaskDel() (Delete self) */
        .
        .
    }
}
```

**ptos** is a pointer to the task's top of stack. The stack is used to store local variables, function parameters, return addresses and CPU registers during an interrupt. The size of this stack is determined by the task's requirements, and the anticipated interrupt nesting. Determining the size of the stack involves knowing how many bytes are required for storage of local variables for the task itself, all nested functions, as well as requirements for interrupts (accounting for nesting). If the configuration constant **OS\_STK\_GROWTH** is set to 1, the stack is assumed to grow downward (i.e. from high memory to low memory). **ptos** will thus need to point to the highest *valid* memory location on the stack. If

**OS\_STK\_GROWTH** is set to 0, the stack is assumed to grow in the opposite direction (i.e. from low memory to high memory).

**prio** is the task priority. A unique priority number must be assigned to each task and the lower the number, the higher the priority (i.e. the importance) of the task.

**id** is the task's ID number. At this time, the ID is not currently used in any other function and has simply been added in **OSTaskCreateExt()** for future expansion. You should set the **id** to the same value as the task's priority.

**pbos** is a pointer to the task's bottom of stack. If the configuration constant **OS\_STK\_GROWTH** is set to 1, the stack is assumed to grow downward (i.e. from high memory to low memory) and thus, **pbos** must point to the lowest *valid* stack location. If **OS\_STK\_GROWTH** is set to 0, the stack is assumed to grow in the opposite direction (i.e. from low memory to high memory) and thus, **pbos** must point to the highest *valid* stack location. **pbos** is used by the stack checking function **OSTaskStkChk()**.

**stk\_size** is used to specify the size of the task's stack (in number of elements). If **OS\_STK** is set to **INT8U**, then **stk\_size** corresponds to the number of bytes available on the stack. If **OS\_STK** is set to **INT16U**, then **stk\_size** contains the number of 16-bit entries available on the stack. Finally, if **OS\_STK** is set to **INT32U**, then **stk\_size** contains the number of 32-bit entries available on the stack.

**pext** is a pointer to a user supplied memory location (typically a data structure) which is used as a TCB extension. For example, this user memory can hold the contents of floating-point registers during a context switch, the time each task takes to execute, the number of times the task is switched-in, etc.

**opt** contains task specific options. The lower 8 bits are reserved by  $\mu$ C/OS-II but you can use the upper 8 bits for application specific options. Each option consists of a bit. The option is selected when the bit is set. The current version of  $\mu$ C/OS-II supports the following options:

**OS\_TASK\_OPT\_STK\_CHK** specifies whether stack checking is allowed for the task.

**OS\_TASK\_OPT\_STK\_CLR** specifies whether the stack needs to be cleared.

**OS\_TASK\_OPT\_SAVE\_FP** specifies whether floating-point registers will be saved the stack needs to be cleared.

you should refer to uCOS\_II.H for other options, i.e. **OS\_TASK\_OPT\_???**.

### Returned Value

**OSTaskCreateExt()** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if the function was successful
- 2) **OS\_PRIO\_EXIST**, if the requested priority already exist

### Notes/Warnings

The stack **MUST** be declared with the **OS\_STK** type.

A task **MUST** always invoke one of the services provided by  $\mu$ C/OS-II to either wait for time to expire, suspend the task or, wait an event to occur (wait on a mailbox, queue or semaphore). This will allow other tasks to gain control of the CPU.

You should not use task priorities **0**, **1**, **2**, **3** and **OS\_LOWEST\_PRIO-3**, **OS\_LOWEST\_PRIO-2**, **OS\_LOWEST\_PRIO-1** and **OS\_LOWEST\_PRIO** because they are reserved for  $\mu$ C/OS-II's use. This thus leaves you with up to 56 application tasks.

### Example #1

The task control block is extended (1) using a 'user defined' data structure called **TASK\_USER\_DATA** (2) which, in this case, contains the name of the task as well as other fields. The task name is initialized with the **strcpy()** standard library function (3). Note that stack checking has been enabled (4) for this task and thus, you are allowed to call **OSTaskStkChk()**. Also, we assume here that the stack grows downward (5) on the processor used (i.e. **OS\_STK\_GROWTH** is set to 1). TOS stands for 'Top-Of-Stack' and BOS stands for 'Bottom-Of-Stack'.

```
typedef struct {                                /* (2) User defined data structure */
    char    TaskName[20];
    INT16U  TaskCtr;
    INT16U  TaskExecTime;
    INT32U  TaskTotExecTime;
} TASK_USER_DATA;

OS_STK      *TaskStk[1024];
TASK_USER_DATA  TaskUserData;

void main(void)
{
    INT8U err;

    .
    OSInit();                                /* Initialize µC/OS-II      */
    .
    strcpy(TaskUserData.TaskName, "MyTaskName"); /* (3) Name of task    */
    err = OSTaskCreateExt(Task,
        (void *)0,
        &TaskStk[1023],                        /* (5) Stack grows down (TOS) */
        10,
        10,
        &TaskStk[0],                          /* (5) Stack grows down (BOS) */
        1024,
        (void *)&TaskUserData,                /* (1) TCB Extension      */
        OS_TASK_OPT_STK_CHK);                 /* (4) Stack checking enabled */
    .
    OSStart();                                /* Start Multitasking     */
}

void Task(void *pdata)
{
    pdata = pdata;                            /* Avoid compiler warning */
    for (;;) {
        .                                    /* Task code              */
        .
    }
}
```

### Example #2

Here we are creating a task but this time, on a processor for which the stack grows upward (1). The Intel MCS-251 is an example of such a processor. It is assumed that `OS_STK_GROWTH` is set to 0. Note that stack checking has been enabled (2) for this task and thus, you are allowed to call `OSTaskStkChk()`. TOS stands for 'Top-Of-Stack' and BOS stands for 'Bottom-Of-Stack'.

```
OS_STK *TaskStk[1024];

void main(void)
{
    INT8U err;

    .
    OSInit();                                /* Initialize µC/OS-II      */
    .
    err = OSTaskCreateExt(Task,
        (void *)0,
        &TaskStk[0],                          /* (1) Stack grows up (TOS) */
        10,
        10,
        &TaskStk[1023],                      /* (1) Stack grows up (BOS) */
        1024,
        (void *)0,
        OS_TASK_OPT_STK_CHK);                /* (2) Stack checking enabled */
    .
    OSStart();                                /* Start Multitasking      */
}

void Task(void *pdata)
{
    pdata = pdata;                            /* Avoid compiler warning  */
    for (;;) {
        .                                    /* Task code                */
        .
    }
}
```

# OSTaskDel()

INT8U OSTaskDel(INT8U prio);

File	Called from	Code enabled by
OS_TASK.C	Task only	OS_TASK_DEL_EN

**OSTaskDel()** allows your application to delete a task by specifying the priority number of the task to delete. The calling task can be deleted by specifying its own priority number or **OS\_PRIO\_SELF** if the task doesn't know its own priority number. The deleted task is returned to the dormant state. The deleted task may be created by calling either **OSTaskCreate()** or **OSTaskCreateExt()** to make the task active again.

## Arguments

**prio** is the task's priority number to delete. You can delete the calling task by passing **OS\_PRIO\_SELF** in which case, the next highest priority task will be executed.

## Returned Value

**OSTaskDel()** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if the task didn't delete itself
- 2) **OS\_TASK\_DEL\_IDLE**, you tried to delete the idle task
- 3) **OS\_TASK\_DEL\_ERR**, the task to delete does not exist
- 4) **OS\_PRIO\_INVALID**, if you specified a task priority higher than **OS\_LOWEST\_PRIO**
- 5) **OS\_TASK\_DEL\_ISR**, you tried to delete a task from an ISR

## Notes/Warnings

**OSTaskDel()** will verify that you are not attempting to delete the  $\mu$ C/OS-II's idle task.

You must be careful when you delete a task that owns resources. Instead, you should consider using **OSTaskDelReq()** which would be a safer approach.

## Example

```
void TaskX(void *pdata)
{
    INT8U err;

    for (;;) {
        .
        .
        err = OSTaskDel(10);           /* Delete task with priority 10    */
        if (err == OS_NO_ERR) {
            .                          /* Task was deleted              */
            .
        }
        .
    }
}
```

```
}  
}  
}
```

# OSTaskDelReq()

INT8U OSTaskDelReq(INT8U prio);

File	Called from	Code enabled by
OS_TASK.C	Task only	OS_TASK_DEL_EN

**OSTaskDelReq()** allows your application to request that a task deletes itself. Basically, you would use **OSTaskDelReq()** when you need to delete a task that can potentially own resources (e.g. the task may own a semaphore). In this case, you don't want to delete the task until the resource is released. The requesting task calls **OSTaskDelReq()** to indicate that the task needs to be deleted. Deletion of the task is, however, deferred to the task being deleted. In other words, the task is actually deleted when it regains control of the CPU. For example, suppose task #10 needs to be deleted. The task desiring to delete this task (example task #5) would call **OSTaskDelReq(10)**. When task #10 gets to execute it would call **OSTaskDelReq(OS\_PRIO\_SELF)** and monitors the returned value. If the return value is **OS\_TASK\_DEL\_REQ** then task #10 is asked to delete itself. At this point, task #10 would call **OSTaskDel(OS\_PRIO\_SELF)**. Task #5 would know whether task #10 has been deleted by calling **OSTaskDelReq(10)** and check the return code. If the return code is **OS\_TASK\_NOT\_EXIST** then task #5 would know that task #10 has been deleted. In this case, task #5 may have to check periodically, though.

## Arguments

**prio** is the task's priority number of the task to delete. If you specify **OS\_PRIO\_SELF**, then you are asking whether another task wants you to be deleted.

## Returned Value

**OSTaskDelReq()** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if the task deletion has been registered
- 2) **OS\_TASK\_NOT\_EXIST**, if the task does not exist. The requesting task can monitor this return code to see if the task actually got deleted.
- 3) **OS\_TASK\_DEL\_IDLE**, you asked to delete the idle task (this is obviously not allowed).
- 4) **OS\_PRIO\_INVALID**, if you specified a task priority higher than **OS\_LOWEST\_PRIO** or, you have not specified **OS\_PRIO\_SELF**.
- 5) **OS\_TASK\_DEL\_REQ**, if a task (possibly another task) requested that the running task be deleted.

## Notes/Warnings

**OSTaskDelReq()** will verify that you are not attempting to delete the  $\mu$ C/OS-II's idle task.

## Example

```
void TaskThatDeletes(void *pdata)          /* My priority is 5          */  
{  
    INT8U err;
```

```

    for (;;) {
        .
        .
        err = OSTaskDelReq(10);      /* Request task #10 to delete itself */
        if (err == OS_NO_ERR) {
            err = OSTaskDelReq(10);
            while (err != OS_TASK_NOT_EXIST) {
                OSTimeDly(1);          /* Wait for task to be deleted      */
            }
            .                          /* Task #10 has been deleted      */
        }
        .
        .
    }
}

void TaskToBeDeleted(void *pdata)    /* My priority is 10            */
{
    .
    .
    pdata = pdata;
    for (;;) {
        OSTimeDly(1);
        if (OSTaskDelReq(OS_PRIO_SELF) == OS_TASK_DEL_REQ) {
            /* Release any owned resources;                                */
            /* De-allocate any dynamic memory;                             */
            OSTaskDel(OS_PRIO_SELF);
        }
    }
}

```

# OSTaskResume()

INT8U OSTaskResume(INT8U prio);

File	Called from	Code enabled by
OS_TASK.C	Task only	OS_TASK_SUSPEND_EN

**OSTaskResume()** allows your application to resume a task that was suspended through the **OSTaskSuspend()** function. In fact, **OSTaskResume()** is the only function that can 'unsuspend' a suspended task.

## Arguments

**prio** specifies the priority of the task to resume.

## Returned Value

**OSTaskResume()** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if the call was successful.

- 2) **OS\_TASK\_RESUME\_PRIO**, the task you are attempting to resume does not exist.
- 3) **OS\_TASK\_NOT\_SUSPENDED**, the task to resume has not been suspended.

#### Notes/Warnings

NONE

#### Example

```
void TaskX(void *pdata)
{
    INT8U err;

    for (;;) {
        .
        .
        err = OSTaskResume(10); /* Resume task with priority 10      */
        if (err == OS_NO_ERR) {
            .                      /* Task was resumed          */
            .
        }
        .
        .
    }
}
```

## OSTaskStkChk()

INT8U OSTaskStkChk(INT8U prio, INT32U \*pfree, INT32U \*pused);

File	Called from	Code enabled by
OS_TASK.C	Task code	OS_TASK_CREATE_EXT

**OSTaskStkChk()** is used to determine a task's stack statistics. Specifically, **OSTaskStkChk()** computes the amount of free stack space as well as the amount of stack space used by the specified task. This function requires that the task be created with **OSTaskCreateExt()** and that you specify **OS\_TASK\_OPT\_STK\_CHK** in the **opt** argument.

Stack sizing is done by 'walking' from the bottom of the stack and counting the number of zero entries on the stack until a non-zero value is found. This of course assumes that the stack is cleared when the task is created. For that purpose, you need to set **OS\_TASK\_STK\_CLR** to 1 in your configuration. You could set **OS\_TASK\_STK\_CLR** to 0 if your startup code clears all RAM and you never delete your tasks. This would reduce the execution time of **OSTaskCreateExt()**.

#### Arguments

**prio** is the priority of the task you desire to obtain stack information about. You can check the stack of the calling task by passing **OS\_PRIO\_SELF**.



**pdata** is a pointer to a variable of type **OS\_STK\_DATA** which contains the following fields.

<b>INT32U</b>	<b>OSFree;</b>	<b>/* Number of bytes free on the stack</b>	<b>*/</b>
<b>INT32U</b>	<b>OSUsed;</b>	<b>/* Number of bytes used on the stack</b>	<b>*/</b>

#### Returned Value

**OSTaskStkChk ( )** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if you specified valid arguments and the call was successful.
- 2) **OS\_PRIO\_INVALID**, if you specified a task priority higher than **OS\_LOWEST\_PRIO**, or you didn't specify **OS\_PRIO\_SELF**.
- 3) **OS\_TASK\_NOT\_EXIST**, if the specified task does not exist.
- 4) **OS\_TASK\_OPT\_ERR**, if you did not specify **OS\_TASK\_OPT\_STK\_CHK** when the task was created by **OSTaskCreateExt ( )** or, you created the task by using **OSTaskCreate ( )**.

#### Notes/Warnings

Execution time of this task depends on the size of the task's stack and is thus non-deterministic.

Your application can determine the total task stack space (in number of bytes) by adding the two fields **.OSFree** and **.OSUsed**.

Technically, this function can be called by an ISR but, because of the possibly long execution time, it is not advisable.

#### Example

```
void Task (void *pdata)
{
    OS_STK_DATA stk_data;
    INT32U      stk_size;

    for (;;) {
        .
        .
        err = OSTaskStkChk(10, &stk_data);
        if (err == OS_NO_ERR) {
            stk_size = stk_data.OSFree + stk_data.OSUsed;
        }
        .
        .
    }
}
```

# OSTaskSuspend()

**INT8U OSTaskSuspend(INT8U prio);**

File	Called from	Code enabled by
OS_TASK.C	Task only	OS_TASK_SUSPEND_EN

**OSTaskSuspend()** allows your application to suspend (or block) execution of a task unconditionally. The calling task can be suspended by specifying its own priority number or **OS\_PRIO\_SELF** if the task doesn't know its own priority number. In this case, another task will need to resume the suspended task. If the current task is suspended, rescheduling will occur and  $\mu$ C/OS-II will run the next highest priority task ready to run. The only way to resume a suspended task is to call **OSTaskResume()**.

Task suspension is additive. This means that if the task being suspended is delayed until 'n' ticks expire then the task will be resumed only when both the time expires and the suspension is removed. Also, if the suspended task is waiting for a semaphore and the semaphore is signaled then the task will be removed from the semaphore wait list (if it was the highest priority task waiting for the semaphore) but execution will not be resumed until the suspension is removed.

### Arguments

**prio** specifies the priority of the task to suspend. You can suspend the calling task by passing **OS\_PRIO\_SELF** in which case, the next highest priority task will be executed.

### Returned Value

**OSTaskSuspend()** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if the call was successful.
- 2) **OS\_TASK\_SUSPEND\_IDLE**, if you attempted to suspend  $\mu$ C/OS-II's idle task. This is of course not allowed.
- 3) **OS\_PRIO\_INVALID**, if you specified a priority higher than the maximum allowed (i.e. you specified a priority  $\geq$  **OS\_LOWEST\_PRIO**) or, you didn't specify **OS\_PRIO\_SELF**.
- 4) **OS\_TASK\_SUSPEND\_PRIO**, if the task you are attempting to suspend does not exist.

### Notes/Warnings

**OSTaskSuspend()** and **OSTaskResume()** must be used in pair.

A suspended task can only be resumed by **OSTaskResume()**.

### Example

```
void TaskX(void *pdata)
{
    INT8U err;

    for (;;) {
        .
        .
        err = OSTaskSuspend(OS_PRIO_SELF);    /* Suspend current task      */
        .                                     /* Execution continues when ANOTHER task .. */
        .                                     /* .. explicitly resumes this task.         */
        .
    }
}
```

# OSTaskQuery()

INT8U OSTaskQuery(INT8U prio, OS\_TCB \*pdata);

File	Called from	Code enabled by
OS_TASK.C	Task or ISR	N/A

**OSTaskQuery()** allows your application to obtain information about a task. Your application must allocate an **OS\_TCB** data structure that will be used to receive a ‘snapshot’ of the desired task’s control block. Your copy will contain *every* field in the **OS\_TCB** structure. You should be careful when accessing the contents of the **OS\_TCB** structure, especially **OSTCBNext** and **OSTCBPrev** because they will point to the next and previous **OS\_TCB** in the chain of created tasks, respectively.

## Arguments

**prio** is the priority of the task you wish to obtain data from. You can obtain information about the calling task by specifying **OS\_PRIO\_SELF**.

**pdata** is a pointer to a structure of type **OS\_TCB** which will contain a copy of the task’s control block.

## Returned Value

**OSTaskQuery()** returns one of these two error codes:

- 1) **OS\_NO\_ERR**, if the call was successful.
- 2) **OS\_PRIO\_ERR**, if you are trying to obtain information from an invalid task.

## Notes/Warnings

The available fields in the task control block depends on the following configuration options (see **OS\_CFG.H**):

```
OS_TASK_CREATE_EN
OS_Q_EN
OS_MBOX_EN
OS_SEM_EN
OS_TASK_DEL_EN
```

## Example

```
void Task (void *pdata)
{
    OS_TCB  task_data;
    INT8U   err;
    void    *pext;
    INT8U   status;

    pdata = pdata;
    for (;;) {
        .
```

```

        .
err = OSTaskQuery(OS_PRIO_SELF, &task_data);
if (err == OS_NO_ERR) {
    pext    = task_data.OSTCBExtPtr; /* Get TCB extension pointer    */
    status = task_data.OSTCBStat;   /* Get task status          */
    .
    .
}
.
.
}
}

```

# OSTimeDly()

void OSTimeDly(INT16U ticks);

File	Called from	Code enabled by
OS_TIME.C	Task only	N/A

**OSTimeDly( )** allows a task to delay itself for a number of clock ticks. Rescheduling always occurs when the number of clock ticks is greater than zero. Valid delays range from 0 to 65535 ticks. A delay of 0 means that the task will not be delayed and **OSTimeDly( )** will return immediately to the caller. The actual delay time depends on the tick rate (see **OS\_TICKS\_PER\_SEC** in the configuration file OS\_CFG.H).

## Arguments

**ticks** is the number of clock ticks to delay the current task.

## Returned Value

NONE

## Notes/Warnings

Note that calling this function with a delay of 0 results in no delay and thus the function returns immediately to the caller. To ensure that a task delays for the specified number of ticks, you should consider using a delay value that is one tick higher. For example, to delay a task for at least 10 ticks, you should specify a value of 11.

## Example

```

void TaskX(void *pdata)
{
    for (;;) {
        .
        .
        OSTimeDly(10);    /* Delay task for 10 clock ticks */
        .
        .
    }
}

```

```
}  
}
```

# OSTimeDlyHMSM()

```
void OSTimeDlyHMSM(INT8U hours, INT8U minutes, INT8U seconds, INT8U milli);
```

File	Called from	Code enabled by
OS_TIME.C	Task only	N/A

**OSTimeDlyHMSM()** allows a task to delay itself for a user specified amount of time specified in hours, minutes, seconds and milliseconds. This is a more convenient and natural format than ticks. Rescheduling always occurs when at least one of the parameters is non-zero.

## Arguments

**hours** is the number of hours that the task will be delayed. The valid range of values is from 0 to 255 hours.

**minutes** is the number of minutes that the task will be delayed. The valid range of values is from 0 to 59.

**seconds** is the number of seconds that the task will be delayed. The valid range of values is from 0 to 59.

**milli** is the number of milliseconds that the task will be delayed. The valid range of values is from 0 to 999. Note that the resolution of this argument is in multiples of the tick rate. For instance, if the tick rate is set to 10 mS then a delay of 5 mS would result in no delay. The delay is actually rounded to the nearest tick. Thus, a delay of 15 mS would actually result in a delay of 20 mS.

## Returned Value

**OSTimeDlyHMSM()** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if you specified valid arguments and the call was successful.
- 2) **OS\_TIME\_INVALID\_MINUTES**, if the minutes argument is greater than 59.
- 3) **OS\_TIME\_INVALID\_SECONDS**, if the seconds argument is greater than 59.
- 4) **OS\_TIME\_INVALID\_MS**, if the milliseconds argument is greater than 999.
- 5) **OS\_TIME\_ZERO\_DLY**, if all four arguments are 0.

## Notes/Warnings

Note that calling this function with a delay of 0 hours, 0 minutes, 0 seconds and 0 milliseconds results in no delay and thus the function returns immediately to the caller. Also, if the total delay time ends up being larger than 65535 clock ticks then, you will not be able to abort the delay and resume the task by calling **OSTimeDlyResume()**.

## Example

```
void TaskX(void *pdata)  
{  
    for (;;) {  
        .  
        .  
    }
```

```

        OSTimeDlyHMSM(0, 0, 1, 0); /* Delay task for 1 second */
        .
        .
    }
}

```

# OSTimeDlyResume()

INT8U OSTimeDlyResume(INT8U prio);

File	Called from	Code enabled by
OS_TIME.C	Task only	N/A

**OSTimeDlyResume()** allows your application to resume a task that has been delayed through a call to either **OSTimeDly()** or **OSTimeDlyHMSM()**.

## Arguments

**prio** specifies the priority of the task to resume.

## Returned Value

**OSTimeDlyResume()** returns one of the following error codes:

- 1) **OS\_NO\_ERR**, if the call was successful.
- 2) **OS\_PRIO\_INVALID**, if you specified a task priority greater than **OS\_LOWEST\_PRIO**.
- 3) **OS\_TIME\_NOT\_DLY**, if the task is not waiting for time to expire.
- 4) **OS\_TASK\_NOT\_EXIST**, if the task has not been created.

## Notes/Warnings

Note that you **MUST NOT** call this function to resume a task that is waiting for an event with timeout. This situation would make the task look like a timeout occurred (unless you desire this effect).

You cannot resume a task that has called **OSTimeDlyHMSM()** with a combined time that exceeds 65535 clock ticks. In other words, if the clock tick runs at 100 Hz then, you will not be able to resume a delayed task that called **OSTimeDlyHMSM(0, 10, 55, 350)** or higher.

(10 Minutes \* 60 + 55 Seconds + 0.35) \* 100 ticks/second

## Example

```

void TaskX(void *pdata)
{
    INT8U err;

    pdata = pdata;
    for (;;) {
        .
        err = OSTimeDlyResume(10); /* Resume task with priority 10 */
    }
}

```

```
        if (err == OS_NO_ERR) {
            .
            .
        }
        .
    }
}
```

# OSTimeGet()

INT32U OSTimeGet(void);

File	Called from	Code enabled by
OS_TIME.C	Task or ISR	N/A

**OSTimeGet()** allows a task obtain the current value of the system clock. The system clock is a 32-bit counter that counts the number of clock ticks since power was applied or since the system clock was last set.

### Arguments

NONE

### Returned Value

The current system clock value (in number of ticks).

### Notes/Warnings

NONE

### Example

```
void TaskX(void *pdata)
{
    INT32U clk;

    for (;;) {
        .
        .
        clk = OSTimeGet(); /* Get current value of system clock */
        .
        .
    }
}
```

# OSTimeSet()

void OSTimeSet(INT32U ticks);

File	Called from	Code enabled by
OS_TIME.C	Task or ISR	N/A

**OSTimeSet ( )** allows a task to set the system clock. The system clock is a 32-bit counter which counts the number of clock ticks since power was applied or since the system clock was last set.

#### Arguments

**ticks** is the desired value for the system clock, in ticks.

#### Returned Value

NONE

#### Notes/Warnings

NONE

#### Example

```
void TaskX(void *pdata)
{
    for (;;) {
        .
        .
        OSTimeSet(0L);    /* Reset the system clock */
        .
        .
    }
}
```

## OSTimeTick()

**void OSTimeTick(void);**

File	Called from	Code enabled by
OS_TIME.C	Task or ISR	N/A

**OSTimeTick ( )** is used to process a clock tick.  $\mu$ C/OS-II checks all tasks to see if they were either waiting for time to expire (because they called **OSTimeDly ( )** or **OSTimeDlyHMSM ( )**) or, are waiting for events to occur until they timeout.

#### Arguments

NONE

#### Returned Value

NONE



### Notes/Warnings

The execution time of **OSTimeTick()** is directly proportional to the number of tasks created in an application. **OSTimeTick()** can be called by either an ISR or a task. If called by a task, the task priority should be VERY high (i.e. have a low priority number) because this function is responsible for updating delays and timeouts.

### Example

(Intel 80x86, RealMode, Large Model)

TickISR	PROC	FAR	
	PUSHA		; Save processor context
	PUSH	ES	
	PUSH	DS	
;			
	INC BYTE PTR	_OSIntNesting	; Notify µC/OS-II of start of ISR
	CALL FAR PTR	_OSTimeTick	; Process clock tick
.			; User Code to clear interrupt
	.		
	CALL FAR PTR	_OSIntExit	; Notify µC/OS-II of end of ISR
	POP	DS	; Restore processor registers
	POP	ES	
	POPA		
;			
	IRET		; Return to interrupted task
TickISR	ENDP		

# OSVersion()

INT16U OSVersion(void);

File	Called from	Code enabled by
OS_CORE.C	Task or ISR	N/A

**OSVersion()** is used to obtain the current version of µ C/OS-II.

### Arguments

NONE

### Returned Value

The version is returned as x.yy multiplied by 100. In other words, version 1.00 is returned as 100.

### Notes/Warnings

NONE

### Example

```
void TaskX(void *pdata)
{
    INT16U os_version;

    for (;;) {
        .
        .
        os_version = OSVersion(); /* Obtain uC/OS-II's version */
        .
        .
    }
}
```

# OS\_ENTER\_CRITICAL()

# OS\_EXIT\_CRITICAL()

File	Called from	Code enabled by
OS_CPU.H	Task or ISR	N/A

**OS\_ENTER\_CRITICAL()** and **OS\_EXIT\_CRITICAL()** are macros which are used to disable and enable the processor's interrupts, respectively.

### Arguments

NONE

### Returned Value

NONE

### Notes/Warnings

These macros must be used in pair.

### Example

```
INT32U Val;

void TaskX(void *pdata)
{
    for (;;) {
```

```
    .  
    .  
    OS_ENTER_CRITICAL(); /* Disable interrupts */  
    .  
    . /* Access critical code */  
    .  
    OS_EXIT_CRITICAL(); /* Enable interrupts */  
    .  
    .  
    }  
}
```

## *Chapter 12*

# *Configuration Manual*

This chapter provides a description of the configurable elements of  $\mu$  C/OS-II. Because  $\mu$  C/OS-II is provided in source form, configuration of  $\mu$  C/OS-II is done through a number of **#define** constants. The **#define** constants are found in a file called **OS\_CFG.H** and should exist for each project/product that you make.

This section describes each of the **#define** constant in the order in which they are found in **OS\_CFG.H**. Table 12-1 provides a summary of these constants and which  $\mu$  C/OS-II functions they affect.

Of course, **OS\_CFG.H** must be included when  $\mu$  C/OS-II is built in order for the desired configuration to take effect.

Service	Set to 1 to enable code	Other config. constant(s) affecting function
<b>Miscellaneous</b>		
OSInit()	N/A	OS_MAX_EVENTS, OS_Q_EN and OS_MAX_QS, OS_MEM_EN, OS_TASK_IDLE_STK_SIZE, OS_TASK_STAT_EN, OS_TASK_STAT_STK_SIZE
OSSchedLock()	N/A	N/A
OSSchedUnlock()	N/A	N/A
OSStart()	N/A	N/A
OSStatInit()	OS_TASK_STAT_EN && OS_TASK_CREATE_EXT_EN	OS_TICKS_PER_SEC
OSVersion()	N/A	N/A
<b>Interrupt Management</b>		
OSIntEnter()	N/A	N/A
OSIntExit()	N/A	N/A
<b>Message Mailboxes</b>		
OSMboxAccept()	OS_MBOX_EN	N/A
OSMboxCreate()	OS_MBOX_EN	OS_MAX_EVENTS
OSMboxPend()	OS_MBOX_EN	N/A
OSMboxPost()	OS_MBOX_EN	N/A
OSMboxQuery()	OS_MBOX_EN	N/A
<b>Memory Partition Management</b>		
OSMemCreate()	OS_MEM_EN	OS_MAX_MEM_PART
OSMemGet()	OS_MEM_EN	N/A
OSMemPut()	OS_MEM_EN	N/A
OSMemQuery()	OS_MEM_EN	N/A
<b>Message Queues</b>		
OSQAccept()	OS_Q_EN	N/A
OSQCreate()	OS_Q_EN	OS_MAX_EVENTS, OS_MAX_QS
OSQFlush()	OS_Q_EN	N/A
OSQPend()	OS_Q_EN	N/A
OSQPost()	OS_Q_EN	N/A
OSQPostFront()	OS_Q_EN	N/A
OSQQuery()	OS_Q_EN	N/A

Table 12-1a

Service	Set to 1 to enable code	Other config. constant(s) affecting function
<b>Semaphore Management</b>		
OSSemAccept()	OS_SEM_EN	N/A
OSSemCreate()	OS_SEM_EN	OS_MAX_EVENTS
OSSemPend()	OS_SEM_EN	N/A
OSSemPost()	OS_SEM_EN	N/A
OSSemQuery()	OS_SEM_EN	N/A
<b>Task Management</b>		
OSTaskChangePrio()	OS_TASK_CHANGE_PRIO_EN	OS_MAX_TASKS
OSTaskCreate()	OS_TASK_CREATE_EN	OS_MAX_TASKS
OSTaskCreateExt()	OS_TASK_CREATE_EXT_EN	OS_MAX_TASKS, OS_TASK_STK_CLR
OSTaskDel()	OS_TASK_DEL_EN	OS_MAX_TASKS
OSTaskDelReq()	OS_TASK_DEL_EN	OS_MAX_TASKS
OSTaskResume()	OS_TASK_SUSPEND_EN	OS_MAX_TASKS
OSTaskStkChk()	OS_TASK_CREATE_EXT_EN	OS_MAX_TASKS
OSTaskSuspend()	OS_TASK_SUSPEND_EN	OS_MAX_TASKS
OSTaskQuery()		OS_MAX_TASKS
<b>Time Management</b>		
OSTimeDly()	N/A	N/A
OSTimeDlyHMSM()	N/A	OS_TICKS_PER_SEC
OSTimeDlyResume()	N/A	OS_MAX_TASKS
OSTimeGet()	N/A	N/A
OSTimeSet()	N/A	N/A
OSTimeTick()	N/A	N/A
<b>User Defined Functions</b>		
OSTaskCreateHook()	OS_CPU_HOOKS_EN	N/A
OSTaskDelHook()	OS_CPU_HOOKS_EN	N/A
OSTaskStatHook()	OS_CPU_HOOKS_EN	N/A
OSTaskSwHook()	OS_CPU_HOOKS_EN	N/A
OSTimeTickHook()	OS_CPU_HOOKS_EN	N/A

Table 12-1b

# OS\_MAX\_EVENTS

**OS\_MAX\_EVENTS** specifies the maximum number of event control blocks that will be allocated. An event control block is needed for every message mailbox, message queue or semaphore object. For example, if you have 10 mailboxes, 5 queues and 3 semaphores, you must set **OS\_MAX\_EVENTS** to at least 18. If you intend to use either mailboxes, queues and/or semaphores then you MUST set **OS\_MAX\_EVENTS** to at least 2.

# OS\_MAX\_MEM\_PART

**OS\_MAX\_MEM\_PART** specifies the maximum number of memory partitions that will be managed by the memory partition manager found in **OS\_MEM.C**. To use memory partition, however, you will also need to set **OS\_MEM\_EN** to 1. If you intend to use memory partitions then you MUST set **OS\_MAX\_MEM\_PART** to at least 2.

# OS\_MAX\_QS

**OS\_MAX\_QS** specifies the maximum number of message queues that your application will create. To use message queue services, you will also need to set **OS\_Q\_EN** to 1. If you intend to use message queues then you MUST set **OS\_MAX\_QS** to at least 2.

# OS\_MAX\_TASKS

**OS\_MAX\_TASKS** specifies the maximum number of *application* tasks that can exist in your application. Note that **OS\_MAX\_TASKS** cannot be greater than 62 because  $\mu$ C/OS-II reserves two tasks for itself (see **OS\_N\_SYS\_TASKS** in **uCOS\_II.H**). If you set **OS\_MAX\_TASKS** to the exact number of tasks in your system, you will need to make sure that you revise this value when you add additional tasks. Conversely, if you make **OS\_MAX\_TASKS** much higher than your current task requirements (for future expansion), you will be wasting valuable RAM.

# OS\_LOWEST\_PRIO

**OS\_LOWEST\_PRIO** specifies the lowest task priority (i.e. highest number) that you intend to use in your application and is provided to allow you to reduce the amount of RAM needed by  $\mu$  C/OS-II. Remember that  $\mu$  C/OS-II's priorities can go from 0 (highest priority) to a maximum of 63 (lowest possible priority). Setting **OS\_LOWEST\_PRIO** to a value less than 63 means that your application cannot create tasks with a priority number higher than **OS\_LOWEST\_PRIO**. In fact,  $\mu$  C/OS-II reserves priorities **OS\_LOWEST\_PRIO** and **OS\_LOWEST\_PRIO - 1** for itself. Task of priority **OS\_LOWEST\_PRIO** is reserved for the idle task (**OSTaskIdle()**) while priority **OS\_LOWEST\_PRIO - 1** is reserved for the statistic task (**OSTaskStat()**). The priorities of your application tasks can thus take a value between 0 and **OS\_LOWEST\_PRIO - 2** (inclusively). The lowest task priority specified by **OS\_LOWEST\_PRIO** is independent of **OS\_MAX\_TASKS**. For example, you can set **OS\_MAX\_TASKS** to 10 and **OS\_LOWEST\_PRIO** to 32. You can thus have up to 10 application tasks and each of those can have a task priority value between 0 and 30 (inclusively). Note that each task must still have a different priority value. You MUST always set **OS\_LOWEST\_PRIO** to a higher value than the number of application tasks in your system. For example, if you set **OS\_MAX\_TASKS** to 20 and **OS\_LOWEST\_PRIO** to 10 then you will not be able to create more than 8 application tasks (0..7). You will simply be wasting RAM.

## OS\_TASK\_IDLE\_STK\_SIZE

**OS\_TASK\_IDLE\_STK\_SIZE** specifies the size of  $\mu$  C/OS-II's idle task. The size is specified not in bytes but in number of elements. This is because a stack MUST be declared to be of type **OS\_STK**. The size of the idle task stack depends on the processor you are using and the deepest anticipated interrupt nesting level. Very little is being done in the idle task but, you should accommodate for at least enough space to store all processor registers on the stack.

## OS\_TASK\_STAT\_EN

**OS\_TASK\_STAT\_EN** specifies whether or not you will enable  $\mu$  C/OS-II's statistics task as well as its initialization function. When set to 1, the statistic task and the statistic task initialization function are enabled. The statistic task (**OSTaskStat()**) is used to compute the CPU usage of your application. When enabled, **OSTaskStat()** executes every second and computes the 8-bit variable **OSCPUUsage** which provides the percentage of CPU utilization of your application. **OSTaskStat()** calls **OSTaskStatHook()** every time it executes so that you can add your own statistics as needed. See **OS\_CORE.C** for details on the statistics task. The priority of **OSTaskStat()** is always set to **OS\_LOWEST\_PRIO - 1**.

The global variables **OSCPUUsage**, **OSIdleCtrMax**, **OSIdleCtrRun** and **OSStatRdy** will not be declared when **OS\_TASK\_STAT\_EN** is set to 0. This allows you to reduce the amount of RAM needed by  $\mu$  C/OS-II if you don't intend to use the statistic task.



# OS\_TASK\_STAT\_STK\_SIZE

**OS\_TASK\_STAT\_STK\_SIZE** specifies the size of  $\mu$ C/OS-II's statistics task stack. The size is specified not in bytes but in number of elements. This is because a stack is declared as being of type **OS\_STK**. The size of the statistics task stack depends on the processor you are using and the maximum of the following actions:

1. The stack growth associated with performing 32-bit arithmetic
2. The stack growth associated with calling **OSTimeDly()**
3. The stack growth associated with calling **OSTaskStatHook()**
4. The deepest anticipated interrupt nesting level

If you want to run stack checking on this task and determine this task's actual stack requirements then, you must enable code generation for **OSTaskCreateExt()** by setting **OS\_TASK\_CREATE\_EXT\_EN** to 1. Again, the priority of **OSTaskStat()** is always set to **OS\_LOWEST\_PRIO - 1**.

# OS\_CPU\_HOOKS\_EN

This configuration constant indicates whether **OS\_CPU\_C.C** declares the hook functions (when set to 1) or not (when set to 0). Recall that  $\mu$ C/OS-II expects the presence of six functions that can either be defined in the port (i.e. in **OS\_CPU\_C.C**) or by the application code. These functions are:

1. **OSTaskCreateHook()**
2. **OSTaskDelHook()**
3. **OSTaskStatHook()**
4. **OSTaskSwHook()**
5. **OSTimeTickHook()**

# OS\_MBOX\_EN

This constant allows you to enable (when set to 1) or disable (when set to 0) code generation of message mailbox services and data structures. This allows you to reduce the amount of code space when your application does not require the use of message mailboxes.

# OS\_MEM\_EN

This constant allows you to enable (when set to 1) or disable (when set to 0) code generation of  $\mu$ C/OS-II's partition memory manager and its associated data structures. This allows you to reduce the amount of code and data space when your application does not require the use of memory partitions.

# OS\_Q\_EN

This constant allows you to enable (when set to 1) or disable (when set to 0) code generation of  $\mu$ C/OS-II's message queue manager and its associated data structures. This allows you to reduce the amount of code and data space when your application does not require the use of message queues. Note that if **OS\_Q\_EN** is set to 0 then the **#define** constant **OS\_MAX\_QS** is irrelevant.

# OS\_SEM\_EN

This constant allows you to enable (when set to 1) or disable (when set to 0) code generation of  $\mu$ C/OS-II's semaphore manager and its associated data structures. This allows you to reduce the amount of code and data space when your application does not require the use of semaphores.

# OS\_TASK\_CHANGE\_PRIO\_EN

This constant allows you to enable (when set to 1) or disable (when set to 0) code generation of the function **OSTaskChangePrio()**. If your application never changes task priorities once they are assigned then you can reduce the amount of code space used by  $\mu$ C/OS-II by setting **OS\_TASK\_CHANGE\_PRIO\_EN** to 0.

# OS\_TASK\_CREATE\_EN

This constant allows you to enable (when set to 1) or disable (when set to 0) code generation for the **OSTaskCreate()** function. Enabling this function makes  $\mu$ C/OS-II backward compatible with  $\mu$ C/OS's task creation function. If your application always uses **OSTaskCreateExt()** (recommended) then you can reduce the amount of code space used by  $\mu$ C/OS-II by setting **OS\_TASK\_CREATE\_EN** to 0. Note that you MUST set at least one of the two **#defines** **OS\_TASK\_CREATE\_EN** or **OS\_TASK\_CREATE\_EXT\_EN** to 1. If you wish, you can actually use both.

# OS\_TASK\_CREATE\_EXT\_EN

This constant allows you to enable (when set to 1) or disable (when set to 0) code generation of the function **OSTaskCreateExt ( )** which is the extended, and more powerful version of the two task creation functions. If your application never uses **OSTaskCreateExt ( )** then you can reduce the amount of code space used by  $\mu$  C/OS-II's by setting **OS\_TASK\_CREATE\_EXT\_EN** to 0. Note, however, that you need the extended task create function to use the stack checking function **OSTaskStkChk ( )**.

## OS\_TASK\_DEL\_EN

This constant allows you to enable (when set to 1) or disable (when set to 0) code generation of the function **OSTaskDel ( )** which allows you to delete tasks. If your application never uses this function then you can reduce the amount of code space used by  $\mu$  C/OS-II by setting **OS\_TASK\_DEL\_EN** to 0.

## OS\_TASK\_SUSPEND\_EN

This constant allows you to enable (when set to 1) or disable (when set to 0) code generation of the two functions **OSTaskSuspend ( )** and **OSTaskResume ( )** which allows you to explicitly suspend and resume tasks, respectively. If your application never uses these functions then you can reduce the amount of code space used by  $\mu$  C/OS-II by setting **OS\_TASK\_SUSPEND\_EN** to 0.

# OS\_TICKS\_PER\_SEC

This constant specifies the rate at which you will call **OSTimeTick()**. It is up to your initialization code to ensure that **OSTimeTick()** is invoked at this rate. This constant is used by **OSStatInit()**, **OSTaskStat()** and, **OSTimeDlyHMSM()**.

# *Appendix E*

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# *Appendix F*

## *Licensing*

$\mu$  C/OS-II is a great realtime kernel and has proven itself in countless applications all around the world. Also, a number of Colleges and Universities are using  $\mu$  C/OS to teach real-time software.

$\mu$  C/OS-II's source and object code can be freely distributed (to students) by accredited Colleges and Universities without requiring a license, as long as there is no commercial application involved. In other words, no licensing is required if  $\mu$  C/OS-II is used for educational use.

You MUST obtain an 'Object Code Distribution License' to embed  $\mu$  C/OS-II in a commercial product. In other words, you must obtain a license to put  $\mu$  C/OS-II in a product that is sold with the intent to make a profit. There will be a license fee for such situations and you will need to contact me (see below) for pricing.

You MUST obtain an 'Source Code Distribution License' to distribute  $\mu$  C/OS-II's source code. Again, there will be a fee for such a license and you will need to contact me (see below) for pricing.

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## **$\mu$ C/OS-II Web site**

The  $\mu$  C/OS-II WEB site ([www.uCOS-II.com](http://www.uCOS-II.com)) contains the following information:

- News on  $\mu$  C/OS and  $\mu$  C/OS-II,
- Bug fixes,
- Availability of ports,
- Answers to frequently asked questions (FAQs),
- Application notes,
- Books,
- Classes,
- Links to other WEB sites, and